View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by University of Kentucky

University of Kentucky
UKnowledge

KWRRI Research Reports

Kentucky Water Resources Research Institute

4-1981

Modeling Soil Water Contents and Their Effects on Stream Flow in Kentucky

Digital Object Identifier: https://doi.org/10.13023/kwrri.rr.128

Grant W. Thomas
University of Kentucky

Ronald E. Phillips
University of Kentucky

David E. Radcliffe
University of Kentucky

Scott Shepard
University of Kentucky

Right click to open a feedback form in a new tab to let us know how this document benefits you.

Follow this and additional works at: https://uknowledge.uky.edu/kwrri_reports

Part of the Soil Science Commons, and the Water Resource Management Commons

Repository Citation

Thomas, Grant W.; Phillips, Ronald E.; Radcliffe, David E.; and Shepard, Scott, "Modeling Soil Water Contents and Their Effects on Stream Flow in Kentucky" (1981). *KWRRI Research Reports*. 75.
https://uknowledge.uky.edu/kwrri_reports/75

This Report is brought to you for free and open access by the Kentucky Water Resources Research Institute at UKnowledge. It has been accepted for inclusion in KWRRI Research Reports by an authorized administrator of UKnowledge. For more information, please contact UKnowledge@lsv.uky.edu.

Research Report No. 128

MODELING SOIL WATER CONTENTS AND THEIR EFFECTS ON STREAM FLOW IN KENTUCKY

By

Grant W. Thomas
Ronald E. Phillips
Principal Investigators

David E. Radcliffe
Scott Shepard
Graduate Assistants

Project Number: A-073-KY (Completion Report)

Agreement Numbers: 14-34-0001-7038 (FY 1977)
14-34-0001-8019 (FY 1978)
14-34-0001-9019 (FY 1979)
14-34-0001-0119 (FY 1980)

Period of Project: April 1977 - March 1981

University of Kentucky
Water Resources Research Institute
Lexington, Kentucky

The work upon which this report is based was supported in part by funds provided by the Office of Water Research and Technology, United States Department of the Interior, Washington, D. C., as authorized by the Water Research and Development Act of 1978. Public Law 95-467.

April 1981

DISCLAIMER

Contents of this report do not necessarily reflect the views and policies of the Office of Water Research and Technology, United States Department of the Interior, Washington, D. C., nor does mention of trade names or commercial products constitute their endorsement or recommendation for use by the U. S. Government.

ABSTRACT

Soil water contents of eight important soil series in Kentucky were measured periodically during the summer growing season for four years, 1977 through 1980. The soils divided into three groups according to their behavior. The first group (Maury and Crider) is well-drained and never showed excess water above field capacity at any time during the four seasons. The second group (Zanesville, Lowell, Calloway, Grenada and Shelbyville) showed perched water tables at times, especially during the early part of the growing season. The third group was represented by the Huntington soil which has a permanent water table.

The in-situ field capacity or upper limits was determined on numerous samples of the Maury, Crider and Shelbyville soil series. Variation within series was rather low, indicating that samples taken at one site are representative of the soil in general.

A model for estimating the soil water in each 15 cm layer was developed and proved to work very well with both Maury and Crider soils. Lowell soil was predicted poorly by the model, with other soils being intermediate. A variation of the model which assumed that the lowest layer of the Huntington was always at the upper limit due to a permanent water table also worked well.

The water calculated from the model as deep drainage was used as a measure of increase in streamflow and compared to measured streamflow on three watersheds and four soils in 1978 and 1979. The R^2 values ranged from 0.41 to 0.95 and the slope, which ideally should be 1.0, ranged from 0.54 to 1.36. The quantitative measure of streamflow was not satisfactory but the prediction of events was quite good. Modifications in the model that seem to be required include provisions for evaporation from foliage with small rains, higher evapotranspiration at lower soil water contents, less deep drainage with small rains and an aquifer storage factor.

Descriptors: Soil Water*, Soil Types*, Soil Porosity, Soil Profiles, Soil Water Table, Soil Moisture Retention, Subsurface Water

TABLE OF CONTENTS

	PAGE
Introduction	1
Soils	2
Crops	3
Sampling	3
Rainfall	4
Model	5
Results and Discussion	8
Field	8
In-Situ Field Capacity	27
Modeling Available Water	30
Comparing Predicted Deep Drainage With Streamflow	43
Summary and Conclusions	50
Literature Cited	52
Appendix	53

LIST OF FIGURES

		PAGE
Figure 1 -	Volumetric water content with depth for Crider soil, 1980 on four sampling dates (numbers are Julian days).	10
Figure 2 -	Volumetric water content with depth for Calloway soil, 1980, on four sampling dates (numbers are Julian days)	11
Figure 3 -	Volumetric water content with depth for Zanesville soil, 1980, on four sampling dates (numbers are Julian dates).	12
Figure 4 -	Volumetric water content with depth for Huntington soil, 1978, on four sampling dates (numbers are Julian days).	13
Figure 5 -	Total water in profile of Crider soil during four growing seasons, 1977 through 1980.	15
Figure 6 -	Total water in profile of Calloway soil during four growing seasons, 1977 through 1980.	16
Figure 7 -	Total water in profile of Huntington soil during four growing seasons, 1977 through 1980.	17
Figure 8 -	Upper and lower water limits for Maury soil.	18
Figure 9 -	Upper and lower water limits for Crider soil.	19
Figure 10 -	Upper and lower water limits for Zanesville soil.	20
Figure 11 -	Upper and lower water limits for Grenada soil.	21
Figure 12 -	Upper and lower water limits for Calloway soil.	22
Figure 13 -	Upper and lower water limits for Lowell soil.	23

Figure 14 - Upper and lower water limits for Shelbyville soil. 24

Figure 15 - Upper and lower water limits for Huntington soil. 25

Figure 16 - Flow diagram of the model. 38

LIST OF TABLES

			PAGE
Table 1	-	Soil locations sampled for soil water over a four-year period (1977-1980) during the months of May through October.	6
Table 2	-	Crops grown on each soil each year of sampling	7
Table 3	-	Available water in field for eight soils estimated from four years of data and field and laboratory lower limits.	28
Table 4	-	In-situ field capacities of Maury, Shelbyville and Maury soils.	29
Table 5	-	Average sums of squares of deviations (x10,000) between actual and predicted volumetric water contents.	41
Table 6	-	Comparison of deviations sums of squares for three assumptions about Huntington soil.	42
Table 7	-	Predicted and observed streamflow from South Elkhorn Creek (Maury soil).	47
Table 8	-	Predicted and observed streamflow from West Fork, Clarks River (Grenada soil).	48
Table 9	-	Predicted and observed streamflow from Muddy Fork, Little River (Crider and Zanesville soils)	49

I. INTRODUCTION:

The water stored in the soil profile above a permanent water table, the so-called vadose zone, is very important first as a source of water for plants and secondly as it influences the incoming water from rainfall. In general, as soil water increases, it is more difficult for rainwater to infiltrate the soil. This can result in surface runoff or overland flow, especially when the soil surface is extremely wet.

During the months from May through October there tends to be a deficit in soil water in Kentucky due to the fact that evapotranspiration exceeds rainfall on the average. However, each year is somewhat different both in solar radiation, which directly influences evapotranspiration, and in rainfall. Therefore a four-year study offered a chance to look at year-to-year variation in soil water behavior.

The present study was undertaken to get information on the relationship between soil water content and stream flow and further to determine the lower and upper limits of water in soils which cover large areas of Kentucky. Finally, it was proposed to model soil water content with depth so that, in the future, soil water could be estimated rather than measured directly in the field. If this could be done accurately enough for practical use, the financial savings would be very great.

II. MATERIALS AND METHODS

A. SOILS

The soils sampled in this study were selected on the basis of land area in Kentucky and the drainage and water table properties of each soil. Originally it was proposed to study six soils, but at two locations there were opportunities to sample related soils so that the number was increased to eight. All sampling sites were located in corn, wheat and/or soybean fields because the models for estimating soil water content are available only for summer annuals. Because there is so little row crop agriculture in the mountains of eastern Kentucky, the soils selected were located from Lexington and west to Calloway County. The soils, the % area in the state and site descriptions are listed in table 1. Of the total area mapped in Kentucky thus far (11,000,000 acres), these eight soils make up 1,750,000 acres or about 16% of the area. If steep and rough lands are excluded, the proportion of farmed land covered by these eight soils is probably about one-third.

The Maury, Shelbyville and Crider are upland soils with good drainage; the Lowell is an upland soil with a clay subsoil which is well drained but which drains slowly. The Zanesville, Grenada and Calloway all are upland soils which have fragipans which restrict drainage so that "perched" water tables are present in the winter and spring months. The Huntington is an alluvial soil with a permanent water table which gets deeper from June through September, but which apparently contributes a considerable amount of water to the upper part of the soil during the summer, as judged by the results.

B. CROPS

Crops grown on each soil each year are indicated in table 2. Summer crops were always either soybeans or corn, but one location had soybeans following wheat which was harvested in mid June each year. For this reason, the results on Grenada and Calloway are not comparable with the other soils, at least early in the season (May-June). On the Maury soil, no-tillage and conventionally - tilled soils were compared each year. At other locations, there were some differences from year to year, denoted in table 2 by C for conventional, M for minimum and N for no-tillage. All locations received approximately recommended amounts of fertilizers and in no case were nutrient deficiencies evident.

C. SAMPLING

As a rule in Kentucky there is practically no soil moisture deficit before May 15 each year. Therefore this was taken as an approximate starting date for sampling, although the actual date varied from year to year and from place to place. The sampling was continued until the soil water deficit was essentially erased in the fall, a date that carried considerably from year to year. Because this usually occurred after the University Fall semester began, the regularity of sampling towards the end of the season was not as good as during the summer.

Samples were taken with an Oakfield sampler, 2 cm in diameter and 105 cm in length. Generally, samples were taken in 15 cm increments to a total depth of 90 cm. These samples were placed in tin cans with tight fitting covers, transported either to Lexington or Princeton, weighed, oven dried and weighed again to determine water content by weight. Volumetric water was estimated by multiplying these numbers by bulk density, which was determined either using a Lutz sampler or the soil sampling tube.

Water contents at 15 bars were determined in the laboratory for all samples to compare to values found in the field. On three of the soils used (Maury, Shelbyville and Crider) the soil series was sampled extensively to determine the variation in in-situ field capacity. This was done to compare values both within and between soils.

D. RAINFALL

Rainfall gauges were set up at each location beginning in 1977. In addition, at Lexington and Princton, there were official weather stations nearby for added security. Rainfall was collected in recording, weighing rain gauges on the Maury, Shelbyville, Lowell and Crider soils, and with tipping bucket type recording gauges on the Huntington, Zanesville, Grenada and Calloway soils. In general the direct weighing gauges were more reliable, but neither type was a model of reliability. Numerous failures were encountered over the four years, especially with the recorders. In most instances, the suspect rainfall data were replaced by data from the nearest available weather station. Rainfall data are the weakest links in the data chain.

E. MODEL

The data obtained were compared to a soil water model originally developed by Ritchie (1972), revised by Duncan et al (1974) and further improved by Radcliffe et al (1980) as a part of this project. In some cases other modifications have been made by Shepard to take into account particular soil properties. Basically, the model requires radiation, maximum and minimum temperatures and a measure (or estimation) of leaf area index (LAI) for estimating loss in soil water. The model operates between the upper and lower water contents found in the field, so there is built into it a site specific bias.

TABLE 1

Soil locations sampled for soil water over a four-year period (1977-80) during the months of May through October.

SOIL SERIES	% OF STATE MAPPED	COUNTY	LANDOWNER	CHARACTERISTICS OF SOIL AND LOCATION
Maury sil	0.99	Fayette	University of Kentucky	Well-drained upland soil from high phosphate limestone. Both conventional and no-tillage plots sampled.
Shelbyville sil	0.65	Shelby	Ellis Brothers	Well-drained upland soil from loess and high phosphate limestone.
Lowell sicl	3.39	Shelby	Ellis Brothers	Slowly drained upland soil from shale, found in same field as Shelbyville.
Huntington sicl	1.13	Hancock	Reynolds	First bottom soil from mixed Ohio river alluvium. Permanent water table.
Crider sicl	2.96	Caldwell	University of Kentucky	Well-drained upland soil from loess and limestone.
Zanesville sil	3.23	Caldwell	University of Kentucky	Somewhat poorly drained upland soil with fragipan at 70 cm depth. Formed from loess over shale. Perched water table often present.
Grenada sil	2.56	Calloway	Dodd, Carraway	Moderately well drained upland soil formed from loess. Fragipan at 70 cm depth.
Calloway sil	0.90	Calloway	Dodd, Carraway	Somewhat poorly drained upland soil formed from loess. Same field as Grenada. Fragipan at about 150 cm.
TOTAL	15.81			

T A B L E 2

Crops grown on each soil each year of sampling

SOIL	CROPS PRESENT EACH YEAR			
	1977	1978	1979	1980
Maury sil	Corn (CN)*	Corn (CN)	Corn (CN)	Corn (CN)
Shelbyville sil	Corn (M)	Soybeans (M)	Corn (M)	Soybeans (M)
Lowell sicl	Corn (M)	Soybeans (M)	Corn (M)	Soybeans (M)
Huntington sicl	Corn (C)	Corn (C)	Corn (C)	Corn (C)
Crider sil	Soybeans (N)	Soybeans (N)	Corn (N)	Soybeans (N)
Zanesville sil	Corn (C)	Corn (C)	Corn (C)	Corn (C)
Grenada sil	Wheat-Soybeans (C)	Wheat-Soybeans (C)	Wheat-Soybeans (N)	Wheat - Soybeans (N)
Calloway sil	Wheat-Soybeans (C)	Wheat-Soybeans (C)	Wheat-Soybeans (N)	Wheat-Soybeans (N)

*C = Conventional tillage

M = Minimum tillage (no plowing)

N = No tillage (residue on surface)

III RESULTS AND DISCUSSION:

A. Field

Typical soil water contents with depth for four soils at several different dates are shown in figures 1 through 4. The examples shown were taken during dry years to emphasize differences, but the principles are valid for any year. Figure 1 shows the Crider sil behaviour in 1980. At 142 days (May 20), there was a deficit only in the top 30 cm; at 197 days, the top 45 cm were very dry and all depths to 90 cm had lost water. By 250 days (Sept. 6), most of the change had occurred deep in the soil profile since there was little more water that could be removed by plants in the top 45 cm. By 300 days (October 24) there had been a considerable rewetting of the profile to 60 cm, with only marginal change below that depth.

Figure 2 shows soil water with depth in the Calloway silt loam for 1980. In general, the behavior is similar to that of the Crider except that the deeper layers of the soil (60 to 90 cm) never lost as much water. Part of this was due to a heavy rain in late June, which wet up the entire soil (shown by heavy line in figure 2). In spite of this, by day 239 the upper 45 cm of the soil were very dry once again.

Figure 3, for the Zanesville soil, also in 1980, shows the presence of a perched water table above 75cm and extending up to perhaps 30 cm on day 142 (May 21). At day 197, the effect of the fragipan, located at about 70 cm depth, is still evident on water content. At 250 days, the soil profile is very dry down to the fragipan and some water has been removed by plant roots from the pan itself. After 300 days, the soil has been rewet down to the 75 cm depth but no perched water table is evident.

Figure 4 shows the Huntington soil for 1978. This alluvial soil has a permanent water table, the effects of which are clearly evident on day 152 between 90 and 60 cm. The Huntington soil shows much less variation during the year than the other soils do because it is "sub-irrigated" by the water table. Hence, net water in the profile is never drawn down very much because of the constant influx of new water in the deeper layers. Furthermore, the drying of the Huntington profile is rather uniform with depth, suggesting that the plant roots are developing more deeply than in the other soils.

Total soil water contents during the four growing seasons are shown in figures 5 through 7. Figure 5 shows yearly values for the Crider soil in the years 1977 to 1980. In the excessively wet year of 1979, there were total changes of only 7 cm in the profile between days 136 and 264. In 1977 there was a short but severe deficit which gave a maximum change of 12 cm during the season. In 1978 and 1980, which were both generally dry years, the soil water deficits were

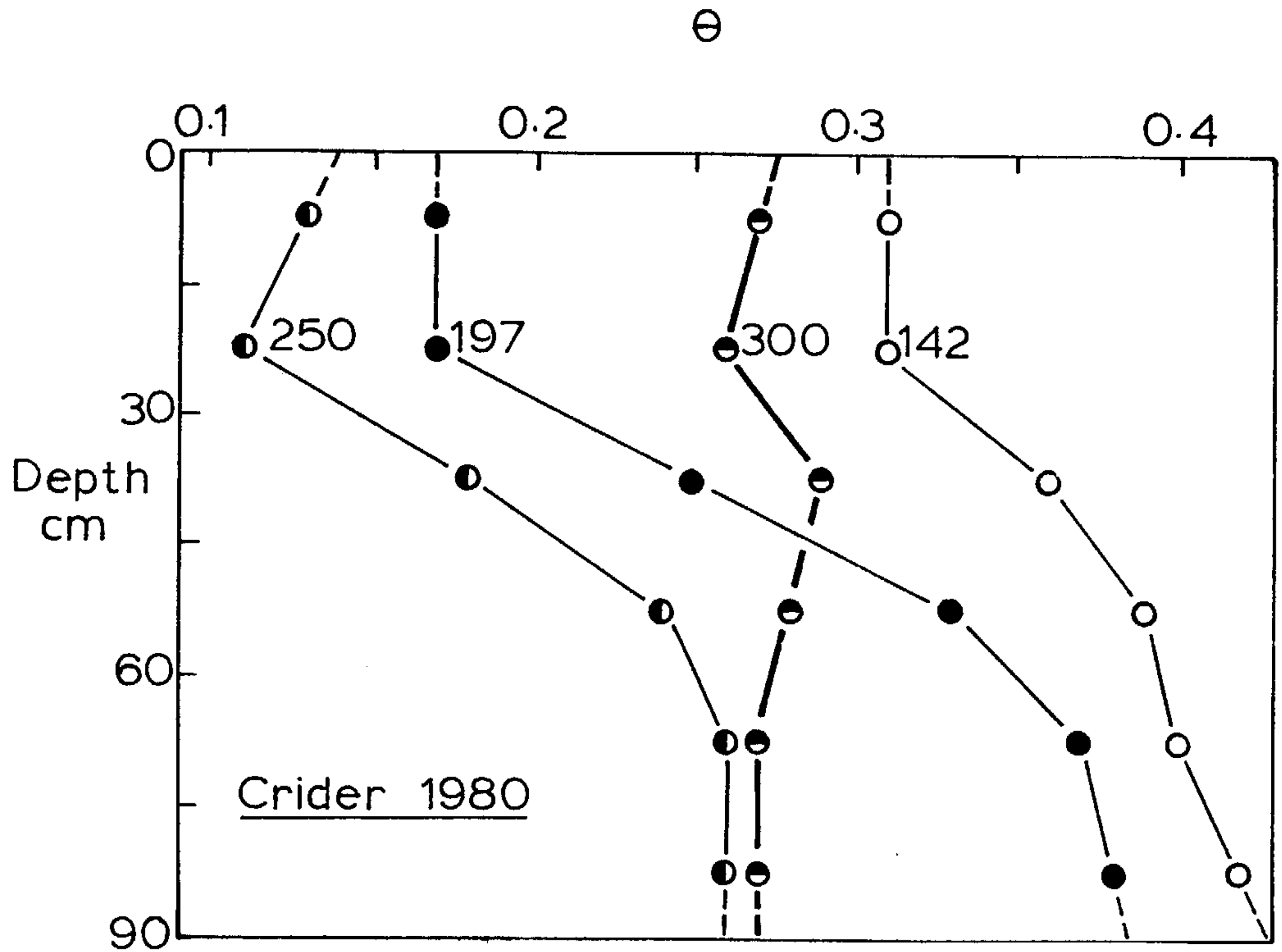

Figure 1. Volumetric Water Content with Depth for Crider Soil, 1980, on Four Sampling Dates (Numbers are Julian Days)

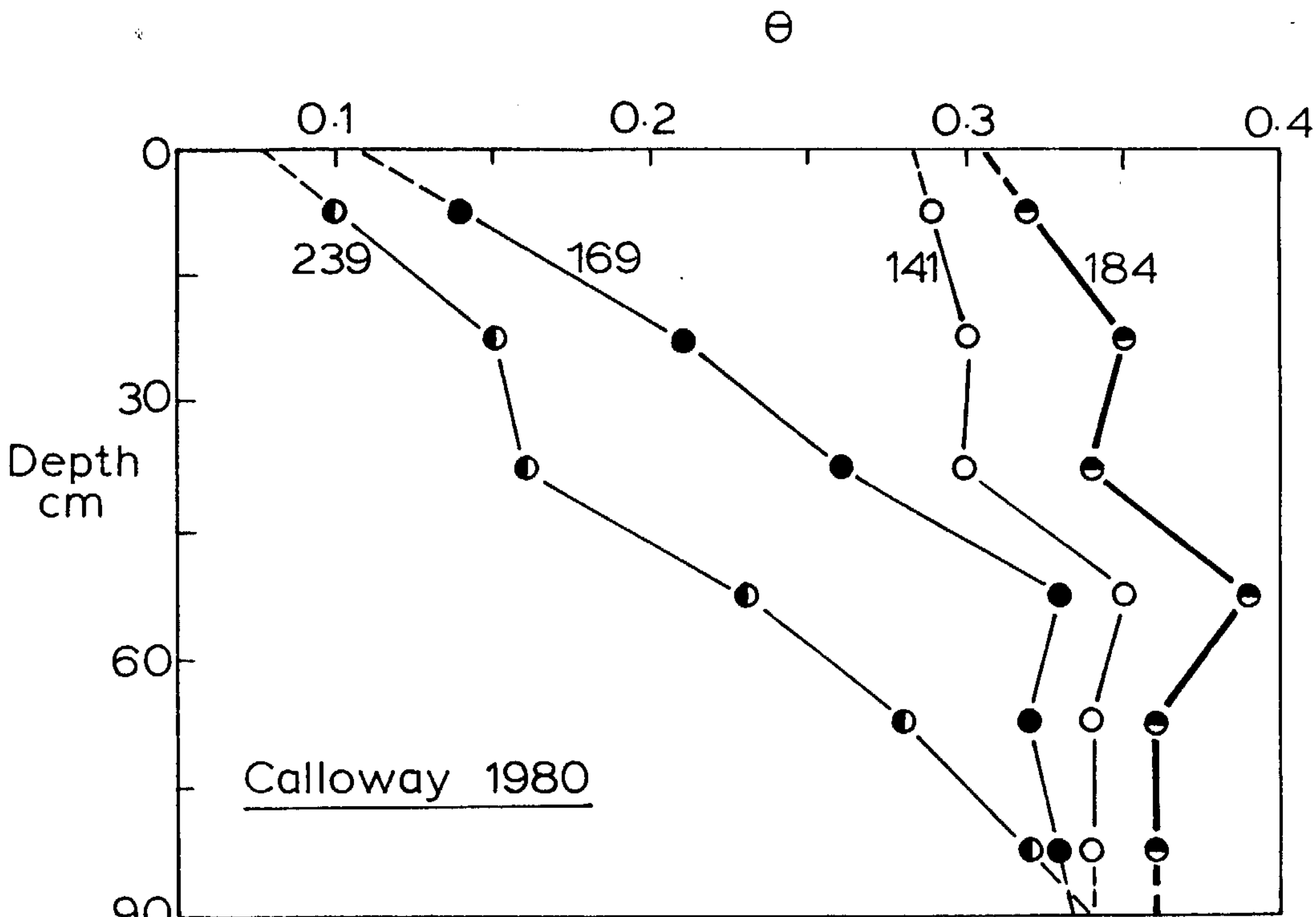

Figure 2. Volumetric Water Content with Depth for Calloway Soil, 1980, on Four Sampling Dates (Numbers are Julian Days)

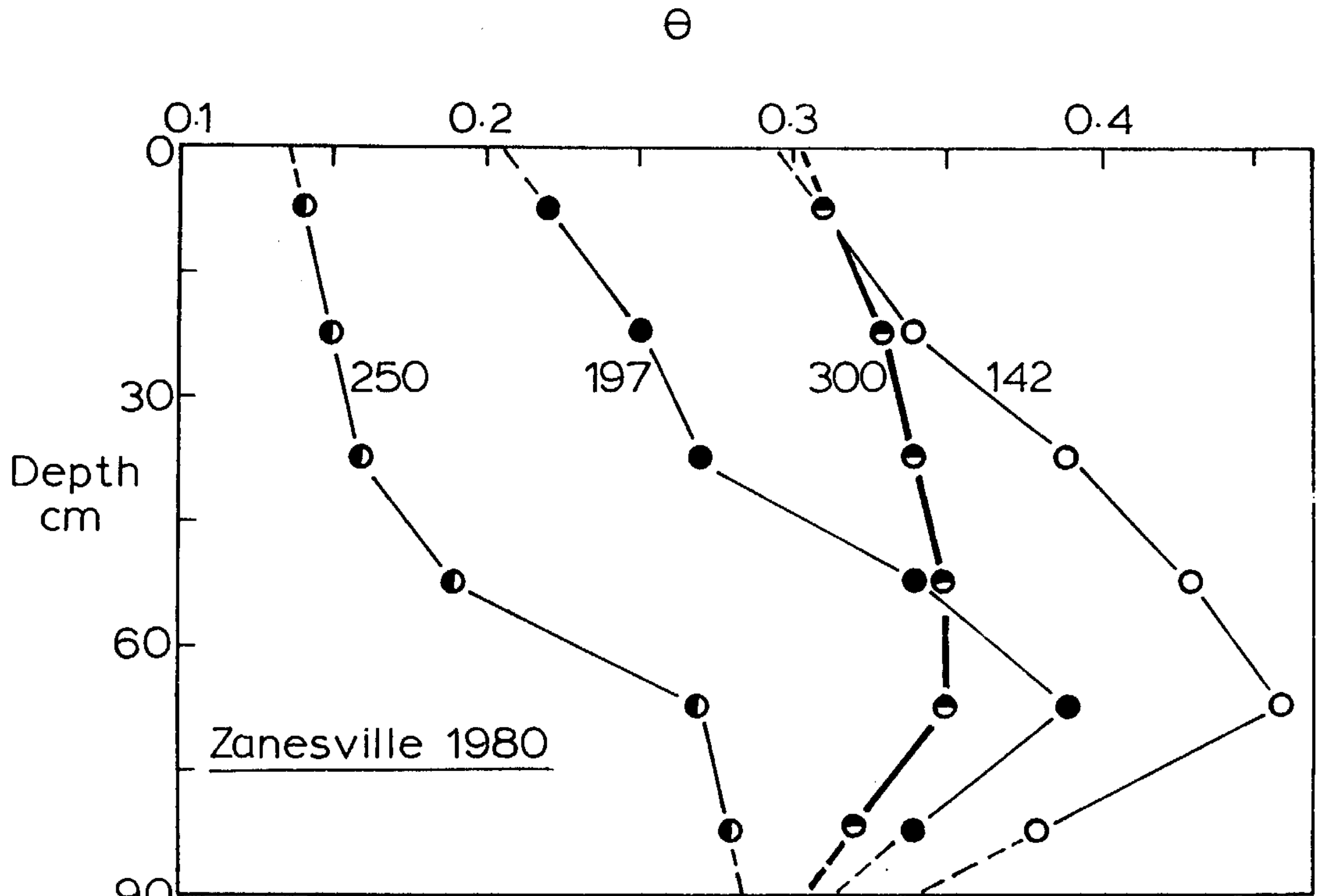

Figure 3. Volumetric Water Content with Depth for Zanesville Soil, 1980, on Four Sampling Dates (Numbers are Julian Days)

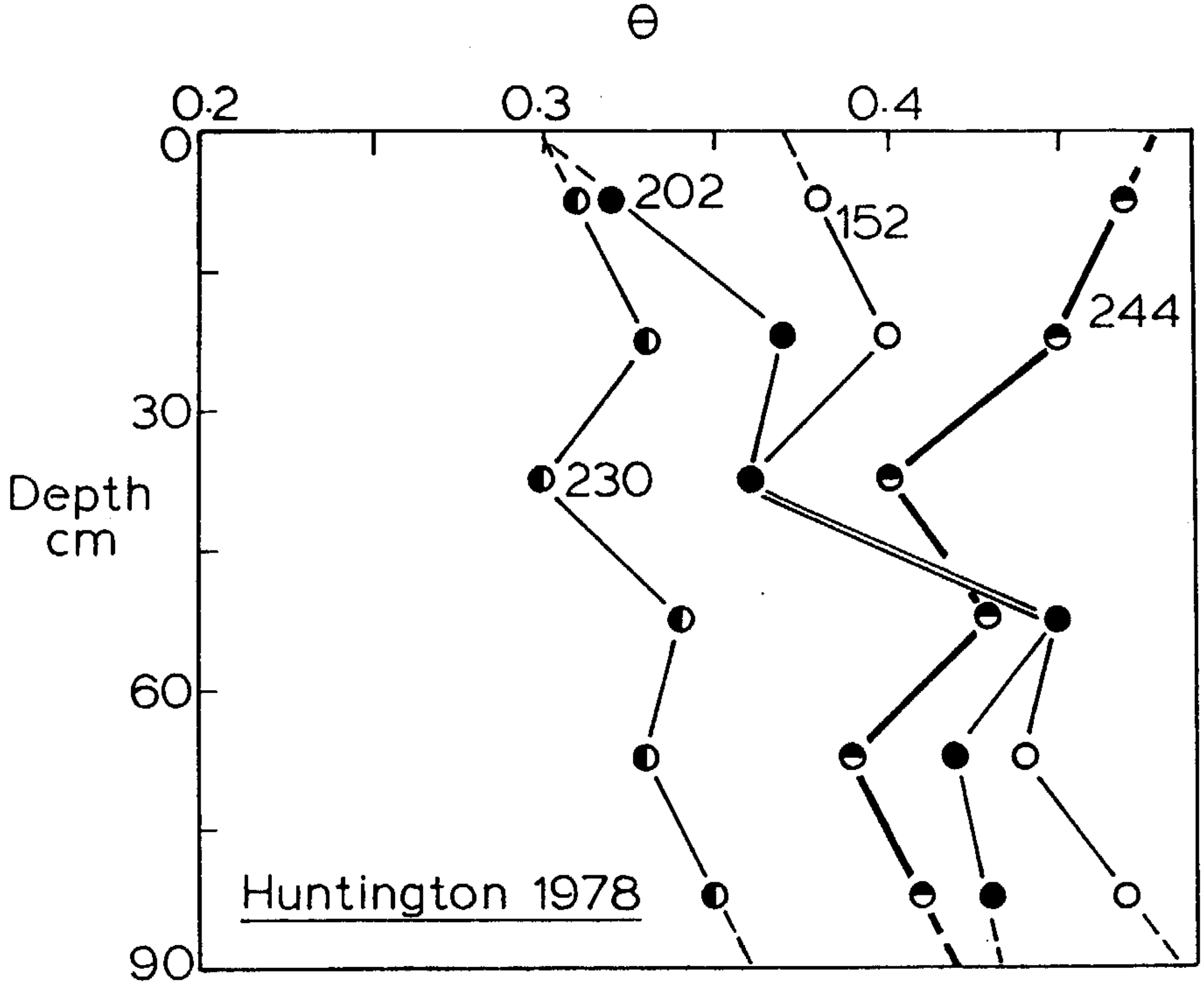

Figure 4. Volumetric Water Content with Depth for Huntington Soil, 1978, on Four Sampling Dates (Numbers are Julian Days)

16 and 15 cm, respectively. These latter two figures probably represent about the maximum deficits possible in this soil. Figure 6 shows similar data for the Calloway soil. Deficit in the wet year of 1979 was only a maximum of 6 cm, whereas in 1977, 1978 and 1980 it was about 15,15 and 13, respectively. In figure 7, the Huntington soil shows a strong contrast to the soils previously discussed. In all four years, wet or dry, the general pattern was identical with major variation occurring only between 240 and 270 days (September) Maximum variation for 1977 through 1980 was 5,12,6 and 8 cm during the four years so that only in 1978 was a major deficit encountered. The other five soils (not shown) were similar to the Crider.

From data such as those shown in previous figures, it is possible to construct graphs showing the upper and lower limits of soil water in the field. These graphs are shown in figures 8 through 15 for all eight soils studied. In general, the soils fall into three groups. The first group, soils that do not hold excess water because they drain rapidly, is represented by the Maury and Crider. This rapid drainage limits the total water changes that occur during the year, particularly in the Maury. The second group tends to hold some excess water (perched water table) in the profile at the upper limit. In the case of the Zanesville soil this effect is very great; in the Grenada and Calloway soils, it is a very slight effect, even though these soils all have fragipans.

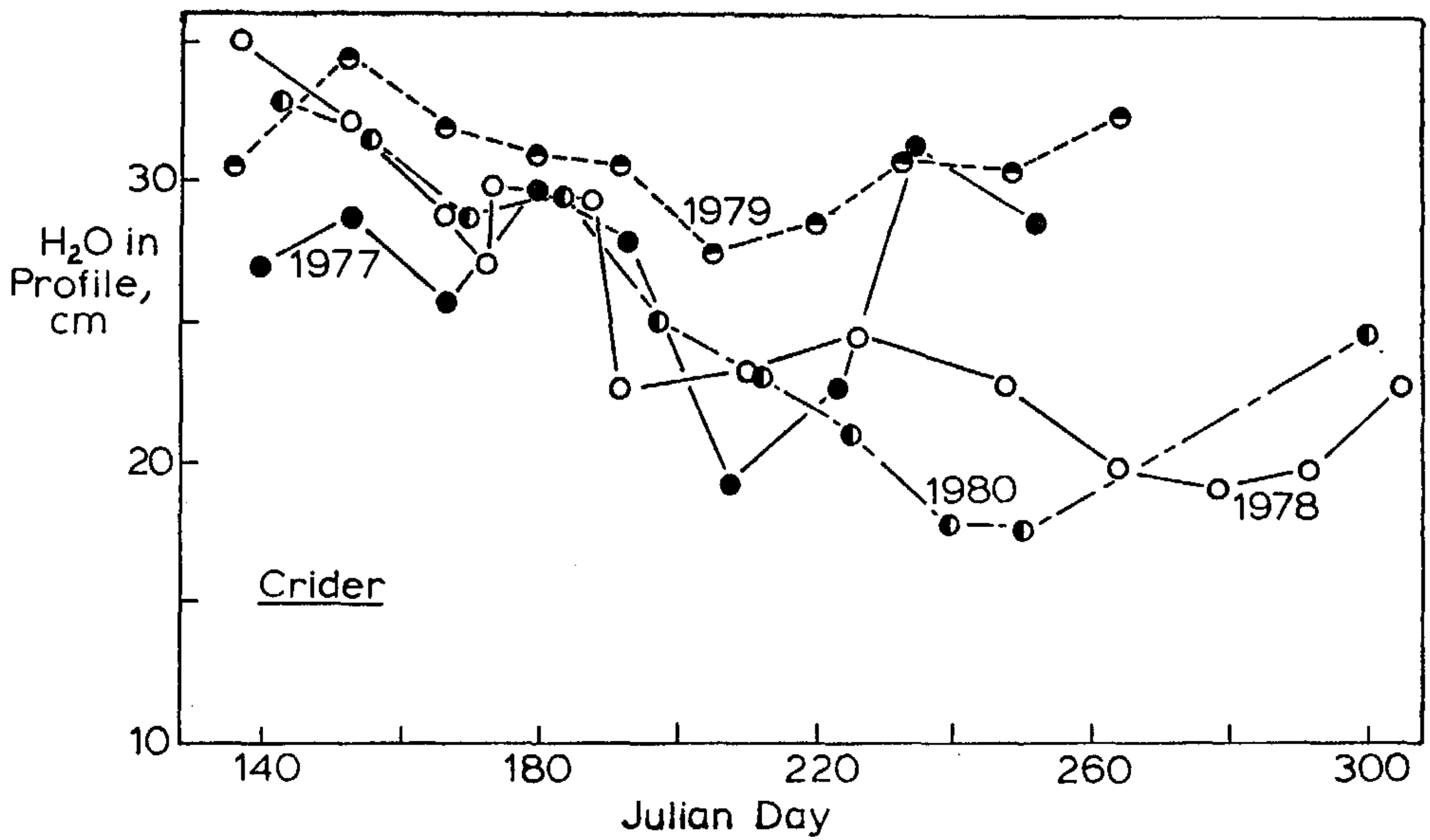

Figure 5. Total Water in Profile of Crider Soil During Four Growing Seasons, 1977 through 1980

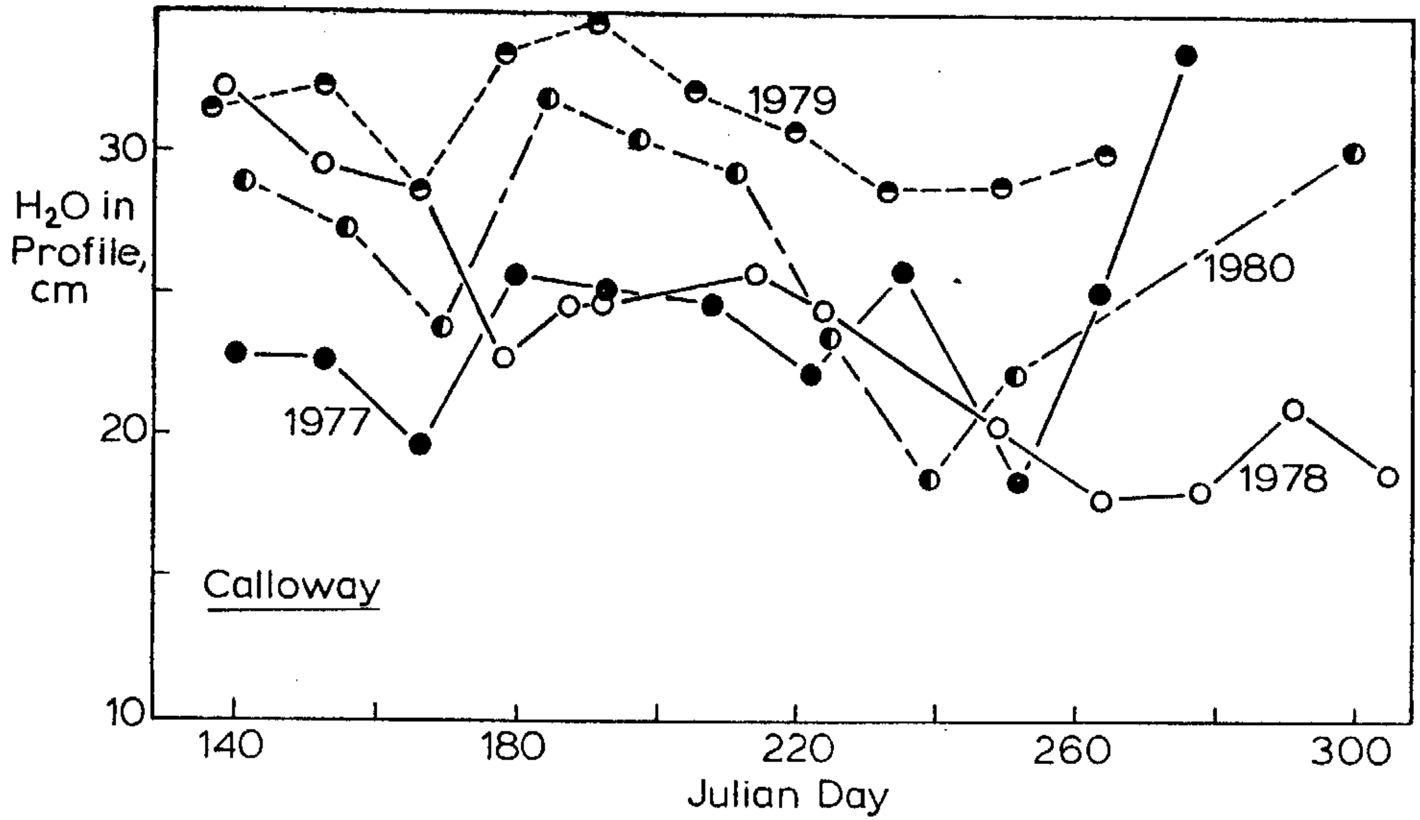

Figure 6. Total Water in Profile of Calloway Soil During Four Growing Seasons, 1977 through 1980

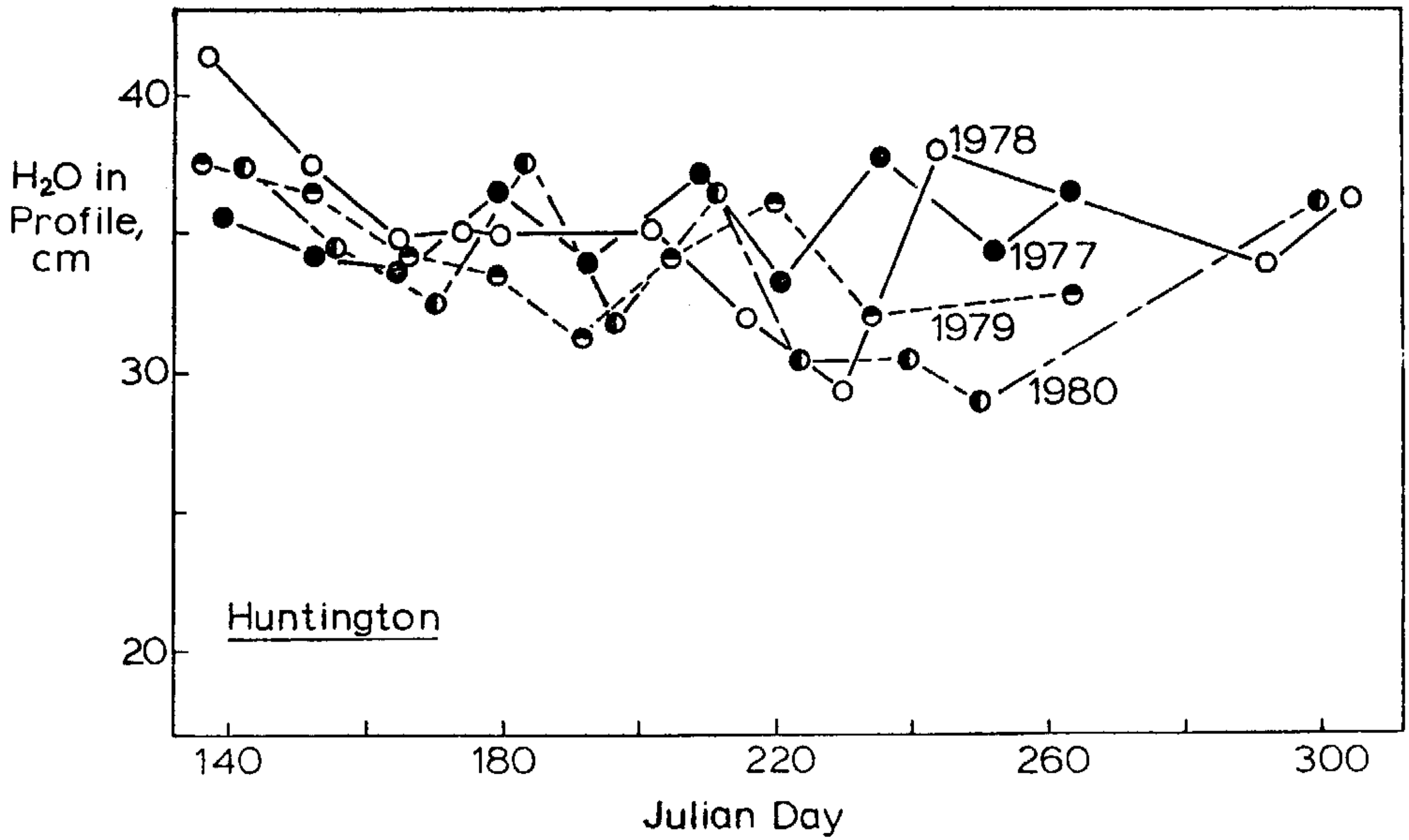

Figure 7. Total Water in Profile of Huntington Soil During Four Growing Seasons, 1977 through 1980

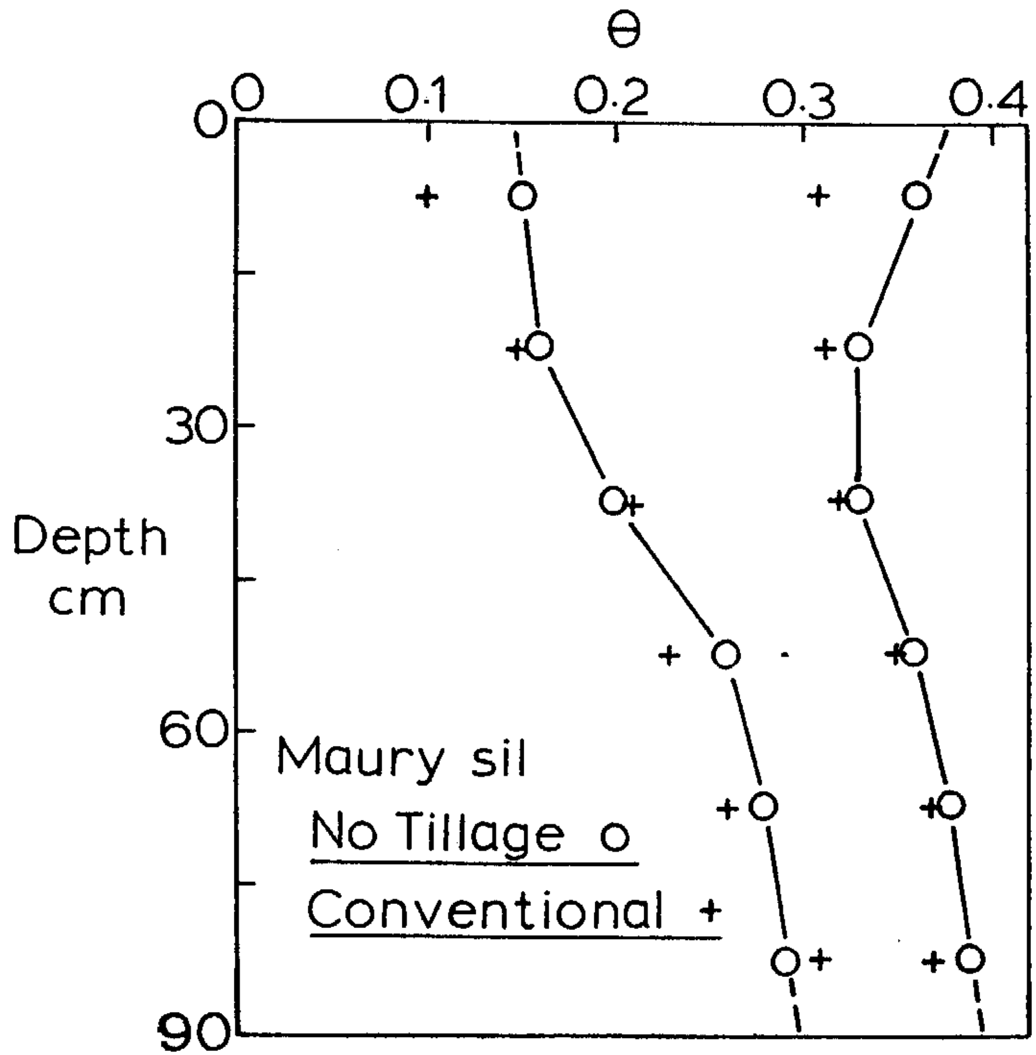

Figure 8. Upper and Lower Water Limits for Muray Soil

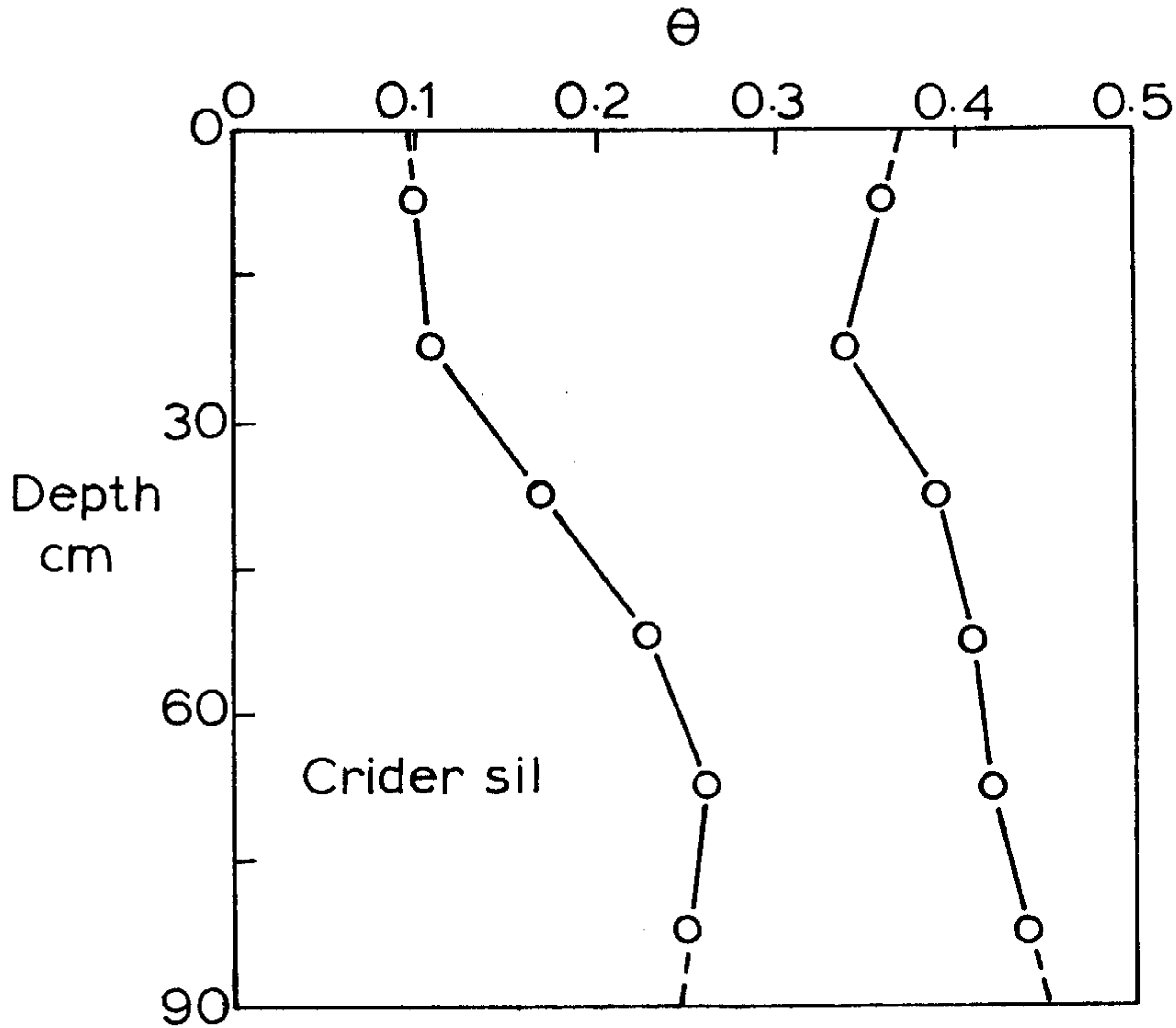

Figure 9. Upper and Lower Water Limits for Crider Soil

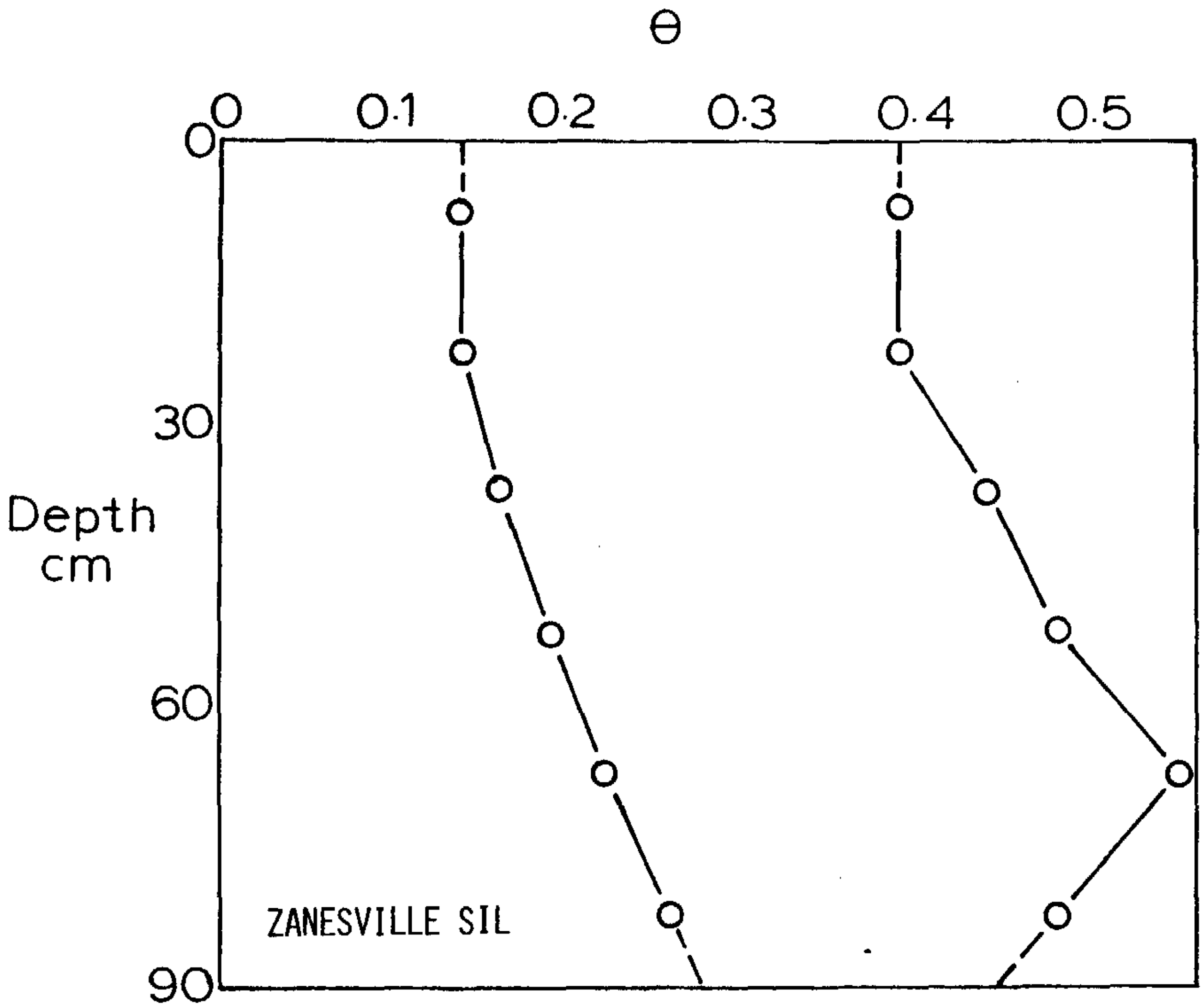

Figure 10. Upper and Lower Water Limits for Zanesville Soil

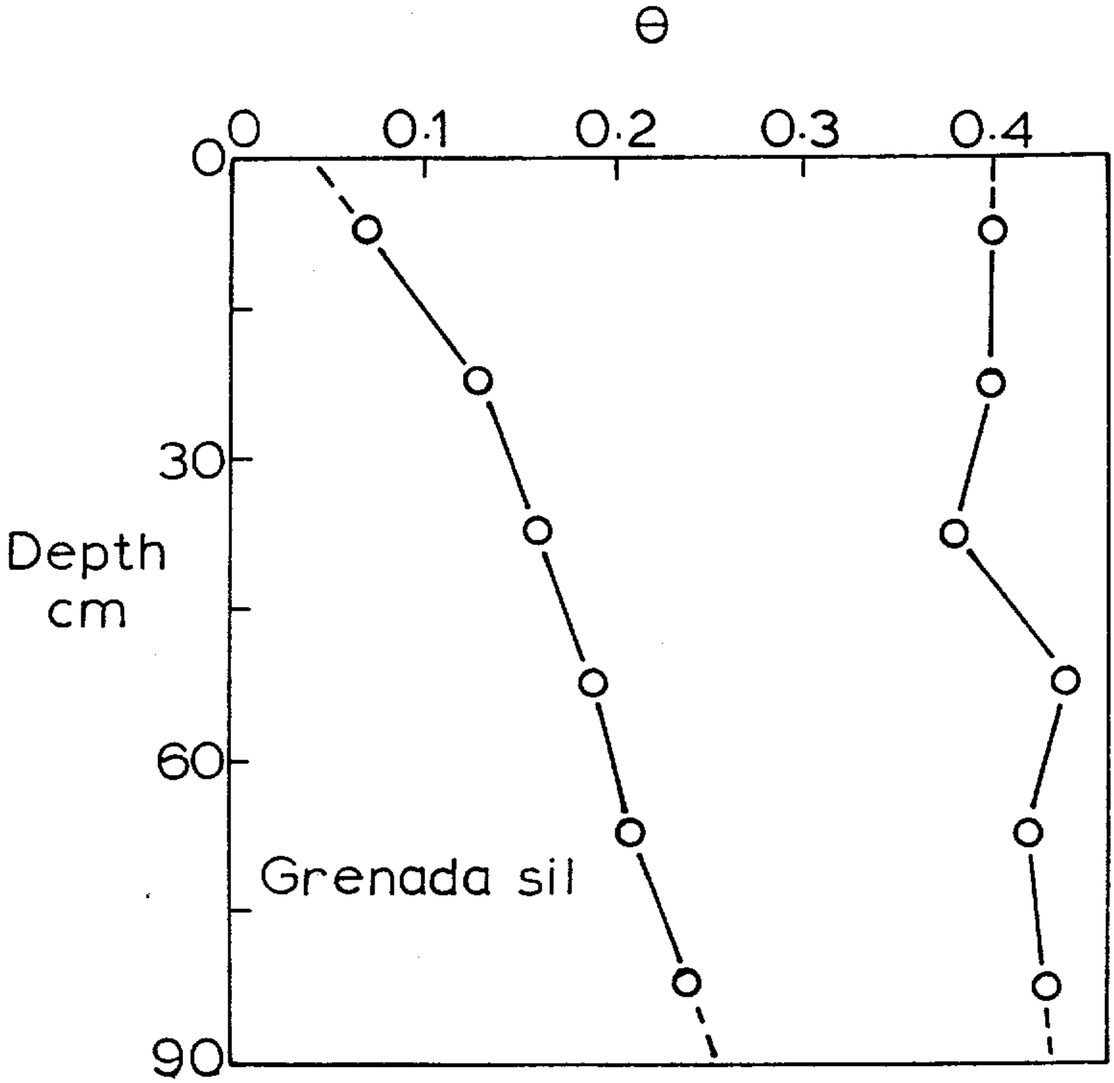

Figure 11. Upper and Lower Water Limits for Grenada Soil

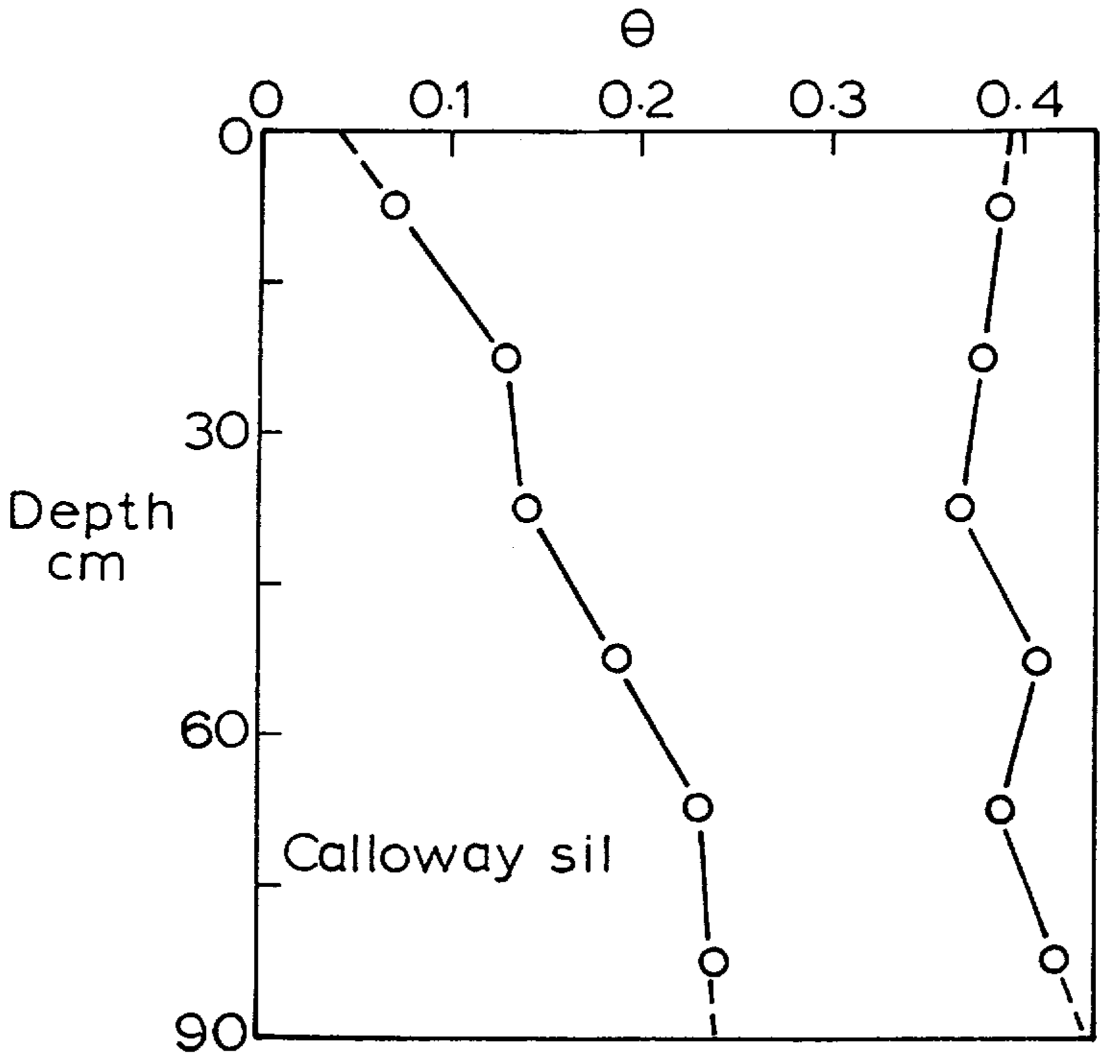

Figure 12. Upper and Lower Water Limits for Calloway Soil

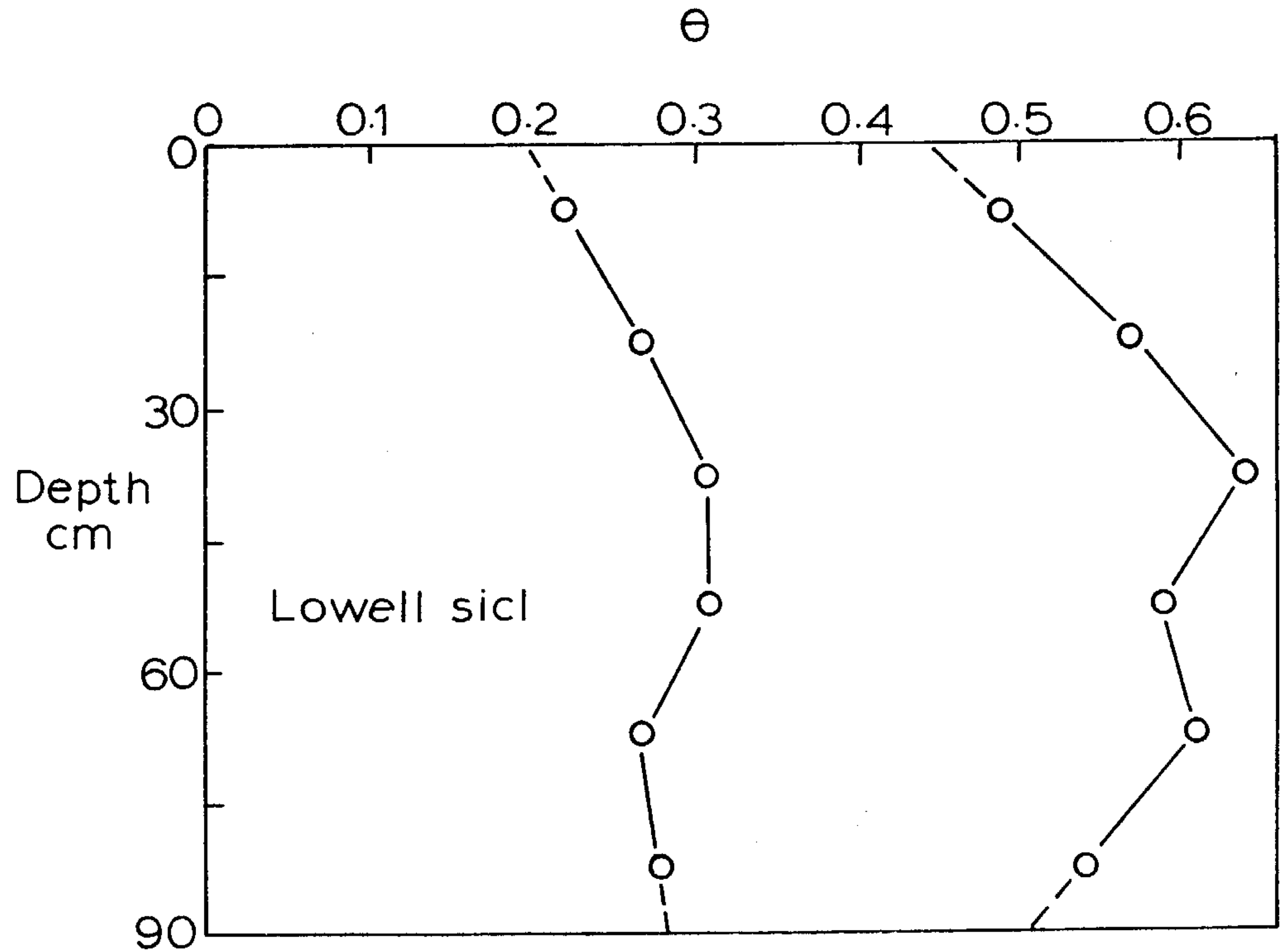

Figure 13. Upper and Lower Water Limits for Lowell Soil

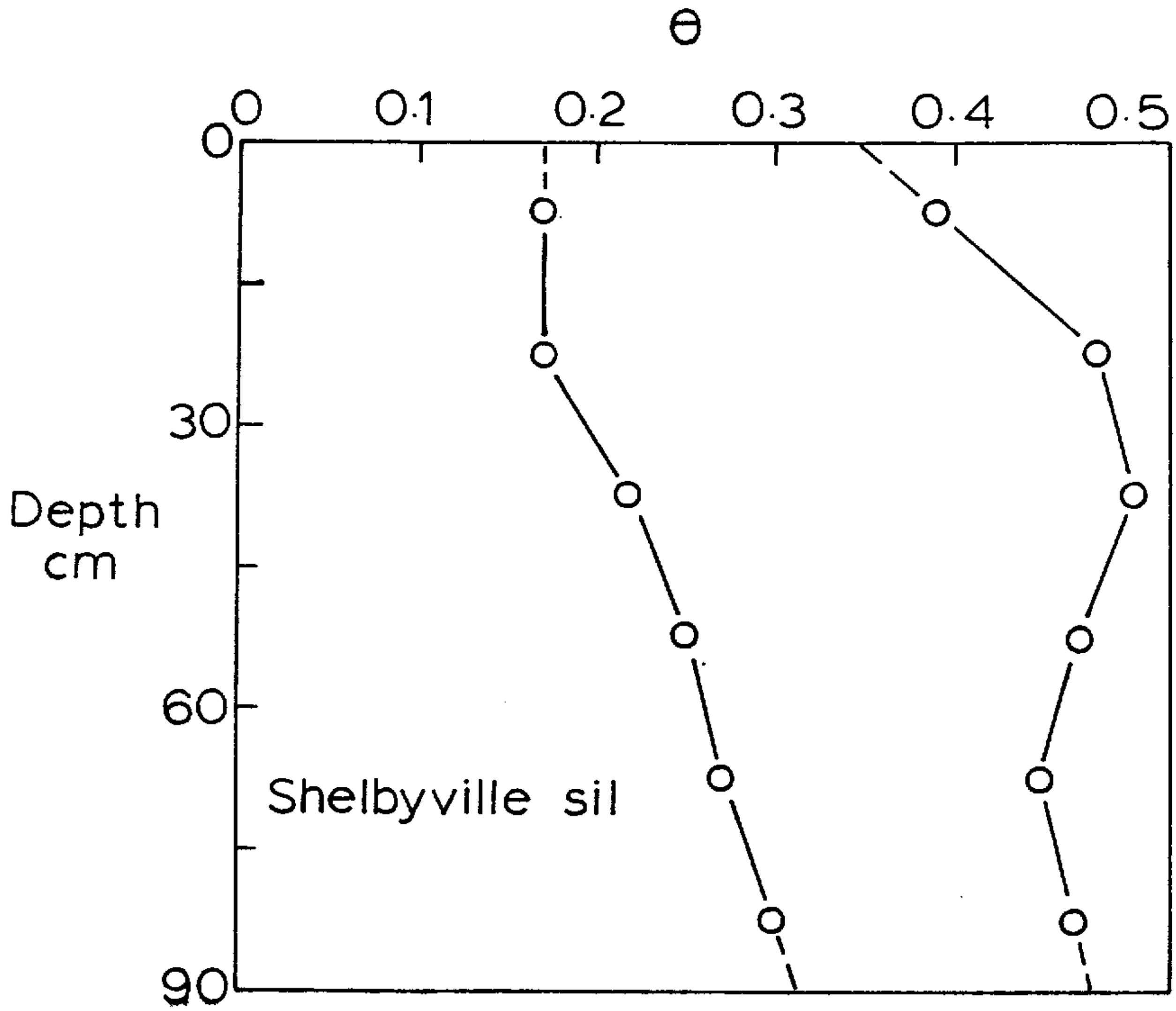

Figure 14. Upper and Lower Water Limits for Shelbyville Soil

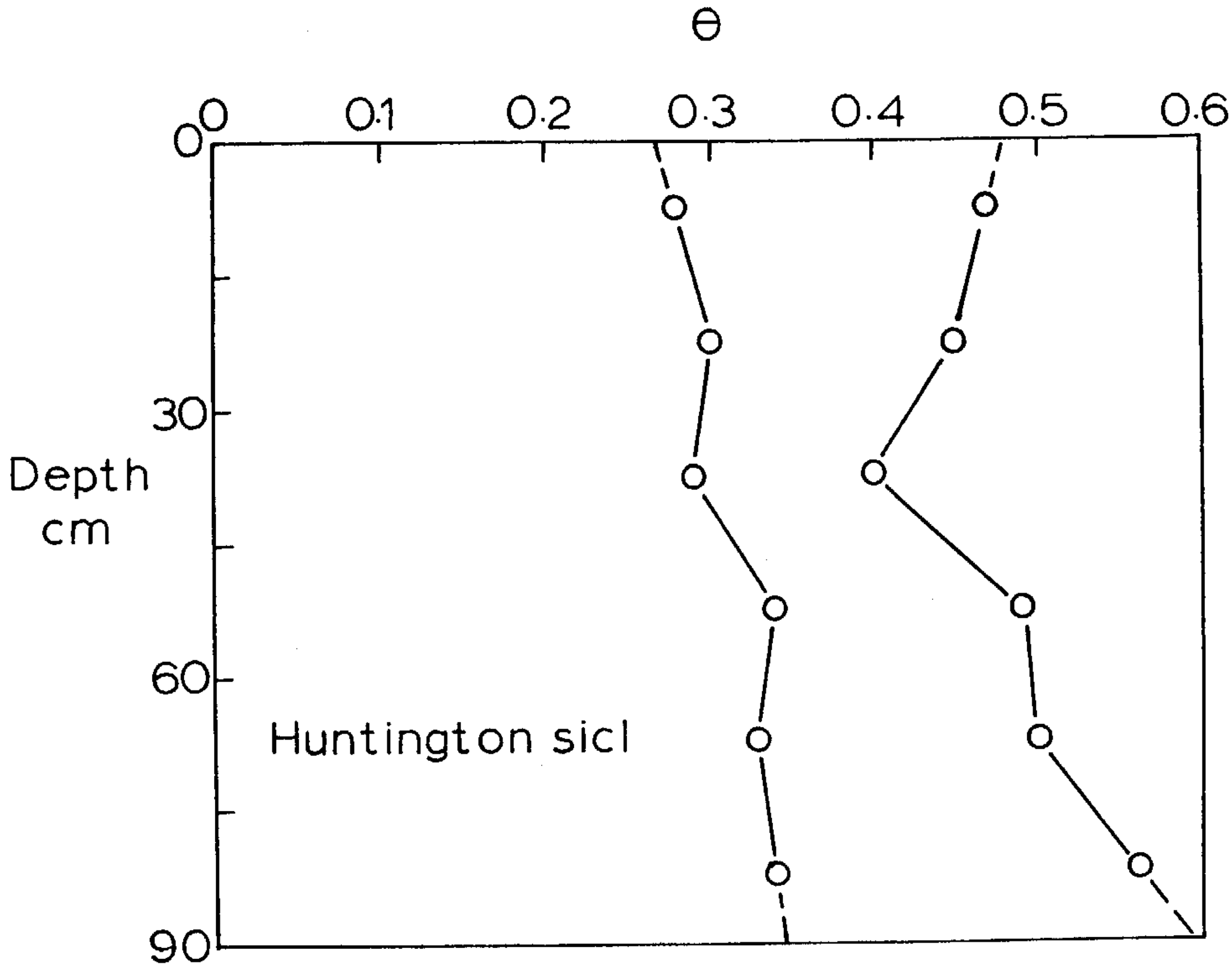

Figure 15. Upper and Lower Water Limits for Huntington Soil

In the Lowell and Shelbyville soils the perched water table is caused by poorly permeable clay in the subsoil and the effect is large for Lowell and small for Shelbyville. Finally, the Huntington soil, with a permanent water table, has a very high lower limit, showing that the water content never approaches the wilting point soil by plant roots.

The differences between upper and lower limits in cm H_2O for each soil are shown in table 3. These differences are the water available to plants (as estimated from four year data) and represent maximum deficits observed. Laboratory and field estimates of the lower limit of water content also are shown in table 3. In general, laboratory estimates are lower than field estimates, indicating that water in field soils does not generally reach a negative potential of 15 bars throughout the profile. There is an especially large discrepancy with the Huntington which does not dry comparably with the other soils because of its permanent water table. The one exception to this is the Lowell soil which gets much drier in the field than 15 bars. These data were rechecked because of their uniqueness and the same results were found for the laboratory analysis. However, in general, the wilting point (15 bar) figures are in the correct order and reflect what happens in the field reasonably well.

Complete data for all eight soils for the four-year period are included in the appendix. These are also the numbers used for comparison with the soil water model.

B. In-situ Field Capacity:

If soil water data are to have general utility over a broad area, a given site must be reasonably representative of other locations where the same soil is located. To test the variability, the in-situ field capacity of three soil types was determined over a broad area. Soils were the Maury, Shelbyville and Crider. Of these soils only the Shelbyville has a slight tendency towards having a perched water table. Therefore, these three soils should give the least variable results out of the eight studied.

Samples were taken using field maps, and verified by USDA soil scientists. Results are presented in table 4. Thirty samples each of Maury and Shelbyville and 8 of Crider were used. Standard deviations were highest at the surface in all three soils as might be expected since the surface layer is subject to rapid changes. All deviations are rather low and most interestingly the water contents of all three soils are quite similar. The inescapable conclusion of this is that not only is one site satisfactory to represent one soil type over a large area, but that one of these soil types can satisfactorily represent all three soils over a large area. This suggests that these three soils, which are rather similar in overall morphology, can be treated as one soil group without losing much precision.

TABLE 3

Available water in field for eight soils estimated from four years of data and field and laboratory lower limits.

Soil	UL - LL (Available Water) in Field	Lower Limit in Lab. (15 bars pressure)	Lower Limit in Field
	Cm H_2O per 90 cm soil depth		
Maury (Conv.)	11.40	17.25	18.90
Maury (no-tillage)	11.55	17.40	20.70
Huntington	14.85	18.30	28.20
Crider	18.90	13.95	16.80
Calloway	20.55	12.60	15.00
Shelbyville	20.70	17.25	20.70
Grenada	21.90	13.65	15.00
Zanesville	24.30	12.90	16.65
Lowell	25.20	30.90	28.20

TABLE 4

In - situ field capacities of Maury, Shelbyville and Maury soils

Soil Depth cm	Maury silt loam, 30 sites		Shelbyville silt loam, 30 sites		Crider silt loam, 8 sites	
	Field Capacity g H_2O/g Soil	Std. Deviation g H_2O/g Soil	Field Capacity g H_2O/g Soil	Std. Deviation g H_2O/g Soil	Field Capacity g H_2O/g Soil	Std. Deviation g H_2O/g Soil
		±		±		±
0 - 15	0.255	0.026	0.246	0.041	0.244	0.020
15 - 30	0.245	0.017	0.231	0.016	0.248	0.011
30 - 45	0.233	0.014	0.228	0.011	0.263	0.004
45 - 60	0.234	0.015	0.233	0.013	0.264	0.005
60 - 75	0.242	0.022	0.237	0.012	0.261	0.009

C. Modeling Available Water:

To test the availability of the water in the two soils, a model was developed that simulated the infiltration, evaporation, transpiration, and deep drainage of soil water under a corn crop. The purpose of the model was to test the validity of assuming different degrees of availability of soil water by comparing model generated water profiles with field measured water profiles for several seasons on each soil.

A simplified flow diagram of the general model is given in figure 1. The four basic components are: potential evapotranspiration, leaf area index, infiltration and distribution of surface water, and uptake of water. Basic crop and soil parameters and daily meteorological data are read into the computer program, and the components (sub-routines in the program) are activated during each one-day time step as follows: first, the leaf area index is computed using a procedure similar to that developed by Duncan et al (1974); next, the potential evapotranspiration component, based on a mdel developed by Ritchie (1972), computes soil evaporation and plant evaporation (transpiration); the infiltration component adjusts the soil profile for rainfall addition using the model of Thomas et al. (1978) to describe the flow of surface water through well structured soil; the uptake component then calculates the actual transpiration and adjusts the soil profile for surface evaporation and transpiration. Finally, the program prints the water content at the end of each day for 15 cm increments down to 90 cm in the soil profile, and the cycle is repeated until the end of the growing season.

The evapotranspiration component uses daily inputs of solar radiation in cal cm^{-2} day^{-1}, maximum and minimum temperatures in ^{o}C, and leaf area index to calculate the soil evaporation and potential plant transpiration for each day. It is adapted from Ritchie's model, which is based on an energy balance approach that assumes the amount of water evaporated from the surface and through the plant will be roughly equal to the potential energy available for evaporation as long as water is not limiting. The solar radiation reaching the canopy and soil surface is converted to latent heat of evaporation using simplified Penman (1948) equations. Evaporation from the soil is equal to the latent heat of evaporation as long as water is freely available at the surface. An amount of water characteristic of the soil is allowed to follow this freely evaporating rate. Below this limit, as a dry layer begins to form, evaporation is less than latent heat and is calculated using a falling rate, also characteristic of the soil. In a similar manner, water used in photosynthesis is ignored and transpiration is considered equal to total latent heat of evaporation less soil evaporation once full canopy (leaf area index $\geq$ 2.7) is achieved. For a developing canopy, an empirical equation relating latent heat, leaf area index, and transpiration is used. Soil evaporation and potential transpiration for the day, both in cm of water, are inputs to the uptake component.

Rather than read in daily measured or tabular values of leaf area index (L_{ai}), as was done in Ritchie's procedure, the proposed model uses a separate component based on the MAIZE model of Duncan et al (1974) to compute the leaf area index of corn. Duncan's algorithm consists of an initial calculation of the maximum leaf area obtainable due to varietal and population considerations and the use of growth curves to compute the daily change in leaf area as a function of physiological days (one physiological day = 21 degree days, with threshold temperatures of 10 and 30°C). The calculation of the maximum leaf area (L_{am}) is accomplished using an equation that Duncan and Hesketh (1969) developed in phytotron studies with different races of corn. They found that the maximum leaf area index (L_{aim}) at plant populations below 29,640 plants ha^{-1} was due to varietal considerations alone, but that a higher planting densities, the leaf area index increased with population. In the model, the maximum leaf area index due to varietal considerations (L_{aiv}) is computed by assuming leaf areas of 90, 110, and 130 dm^2 plant^{-1} for early, intermediate, and full season maturity varieties, respectively. Leaf area is coverted to leaf area index by multiplying by the quotient of the plant population and the number of dm^2 per hectare. The maximum leaf area index as a function of plant density (P) is then computed using the following equations:

$$L_{aim} = L_{aiv} \text{ ; when } P < 29{,}640 \text{ plants ha}^{-1} \qquad (1)$$

$$L_{aim} = 0.000668\, L_{aiv}\, P^{0.71};$$

$$\text{when } P \geq 29{,}640 \text{ plants ha}^{-1} \qquad (2)$$

Duncan and Hesketh (1969) also found that the development of leaf area was closely related to accumulated physiological days, being exponential in the early stage, linear during the middle growth stage, reaching a maximum during tasseling and silking, and declining steadily thereafter.

The slope of the linear portion of the curve was dependent on the maturity classification of the corn, being lower for varieties that matured later in the season. The three separate equations used in the MAIZE subroutine to describe the different types of leaf development were replaced with the following empirical equation for leaf growth up to and including tasseling:

$$L_a = L_{am} L_{ao} / [L_{ao} + (L_{am} - L_{ao}) \exp(-M\, t_p)] \qquad (3)$$

where:

L_a = leaf area on a given day in dm^2 $plant^{-1}$

L_{am} = maximum leaf area in dm^2 $plant^{-1}$ = L_{aim} $(10^6\ dm^2\ ha^{-1})$ $(1/P)$

L_{ao} = leaf area at seedling emergence = 0.2 dm^2 $plant^{-1}$

t_p = accumulated physiological days

M = maturity classification exponent [0.23, 0.20, and 0.17 (physiological days)$^{-1}$ for early, intermediate, and full maturity, respectively].

Ten physiological days after tasseling (which occurred at 55, 63 and 84 physiological days for early, intermediate, and full maturity in the model), leaf area was calculated by assuming a constant declining rate that was independent of physiological days for the remainder of the growing season (Duncan <u>et al</u> 1974):

$$L_a = L_{am} (1 - 0.005\, t_c) \qquad (4)$$

where:

t_c = the number of calendar days after the decline started

The function of the leaf area index component was to make an initial calculation of the maximum leaf area using equation (1) or (2). Thereafter on a daily basis, the change in leaf area was computed using equations (3) and (4) depending on the stage of development. This leaf area was converted to leaf area index and used as an input to the evapotranspiration component.

It was assumed that the distribution of water in the soil profile following the addition of surface water (rain in this case) could be described by the simple chromatographic equations of Thomas et al (1978). They found that these equations accurately described the fraction of tagged water found at each depth following application of tagged artificial rainfall to the soil surface in a well structured soil. In the model, it was assumed that the initial distribution of surface water from rainfall or irrigation would be the same as that described for tagged water. The following equations were adapted from Thomas et al (1978) to provide an empirical distribution of added water:

$$C = C_o \; ; \qquad X/X_t \leq K \qquad (5a)$$

$$C = C_o[1/(1-K)] \, [(K \, X_t/X)^{1/2} - K] \quad X/X_t > K < X_t/X \quad (5b)$$

$$C = 0 \qquad X/X_t \geq 1/K \qquad (5c)$$

where:

C = amount of water that is added at depth X in cm

C_o = field capacity at depth X in cm

X_t = (d/Θ) expected depth of front with complete displacement.

X = any depth of interest

Θ = volumetric water content at field capacity.

d = depth of water added in cm

K = coefficient of displacement $(0 \leq K \leq 1.00)$

These equations were used to calculate the addition of surface water at each level in the profile on days when precipitation occurred. In general, the amount of water added to each depth as a result of a rain or an irrigation event of d cm was calculated using equations (5a) or (5b) depending upon the value of X/X_t. For lower depths $(X/X_t \geq 1/K)$, equation (5c) applied and no water was added. It was assumed that the water was added to each appropriate level and that displacement of the original soil moisture occurred only when the total water at a level exceeded field capacity for that level. A coefficient of displacement (K) of 0.05 was used in the model and this value agreed well with data previously obtained in the field. The component calculated the final profile distribution of water resulting from the rainfall or irrigation and passed this information to the uptake component.

Due to the difficulty in measuring highly variable quantities such as hydraulic conductivity and root surface area with depth, an empirical approach to uptake was investigated. The overall principle of this approach was the assumption that the plant optimized energy expenditures by taking water from the depth of lowest energy level (Wadleigh, 1945). The energy level at each depth on a given day was taken to be the hydraulic head potential (matrix potential plus the gravitational potential). The matrix potential was derived from experimentally determined potential-vs-water-content relationships for each depth of a given soil. Since a single percent decrease in water content can change matrix potential by an order of magnitude, the relative order of energy levels may change as the transpirational water for a given day is withdrawn. To reduce this error without incurring undue cost in computer time, the transpirational demand for each day was divided into four segments. A quarter of the total daily demand for water was taken from the depth with the least negative hydraulic head potential; then the water content at this depth was adjusted for the decrease and the relative order of energy levels was recalculated. The second quarter of water was withdrawn from the new optimum depth (which may or may not have been the same as for the first uptake), and so forth through the remaining quarters. The total amount of water "demand" on a given day was calculated by the evapotranspiration component, based on climatic conditions. Actual transpiration, however, falls below potential as the water content in the profile decreases, slowing the rate of movement of water to the root and increasing the pathlength of flow. To account for this, a relationship, similar to one proposed by Denmead and Shaw (1962), between water content and the fraction of potential water transpired was used:

$$E = E_o\ 0.0001/[0.0001 + 0.9999 \exp(-1.45\ \Theta_{aw})] \qquad (6)$$

where:

E = actual transpiration in cm

E_o = potential transpiration in cm

Θ_{aw} = percent available water at the depth in question

For each day in the model, the potential transpiration (E_o, calculated by the evapotranspiration component) was divided into quarters; then the depth with the most favorable hydraulic head potential was selected, and the amount of actual water withdrawn from that level was a function of the available water in the layer as given by equation (6)

The uptake component adjusts each level as required for loss due to transpiration and evaporation from the surface 15 cm and passes the new moisture levels at the end of the day to the output section.

The flow diagram is shown in figure 16.

The relative accuracy of the different models was measured by computing a mean squared error of prediction for the growing season of each simulation. This error consisted of the sum of the squared deviations between the simulated and the observed water contents divided by the total number of comparisons (number of sampling dates times the number of layers).

The computer model was developed to predict water content in a Maury silt loam with corn grown with conventional tillage, and all the fit

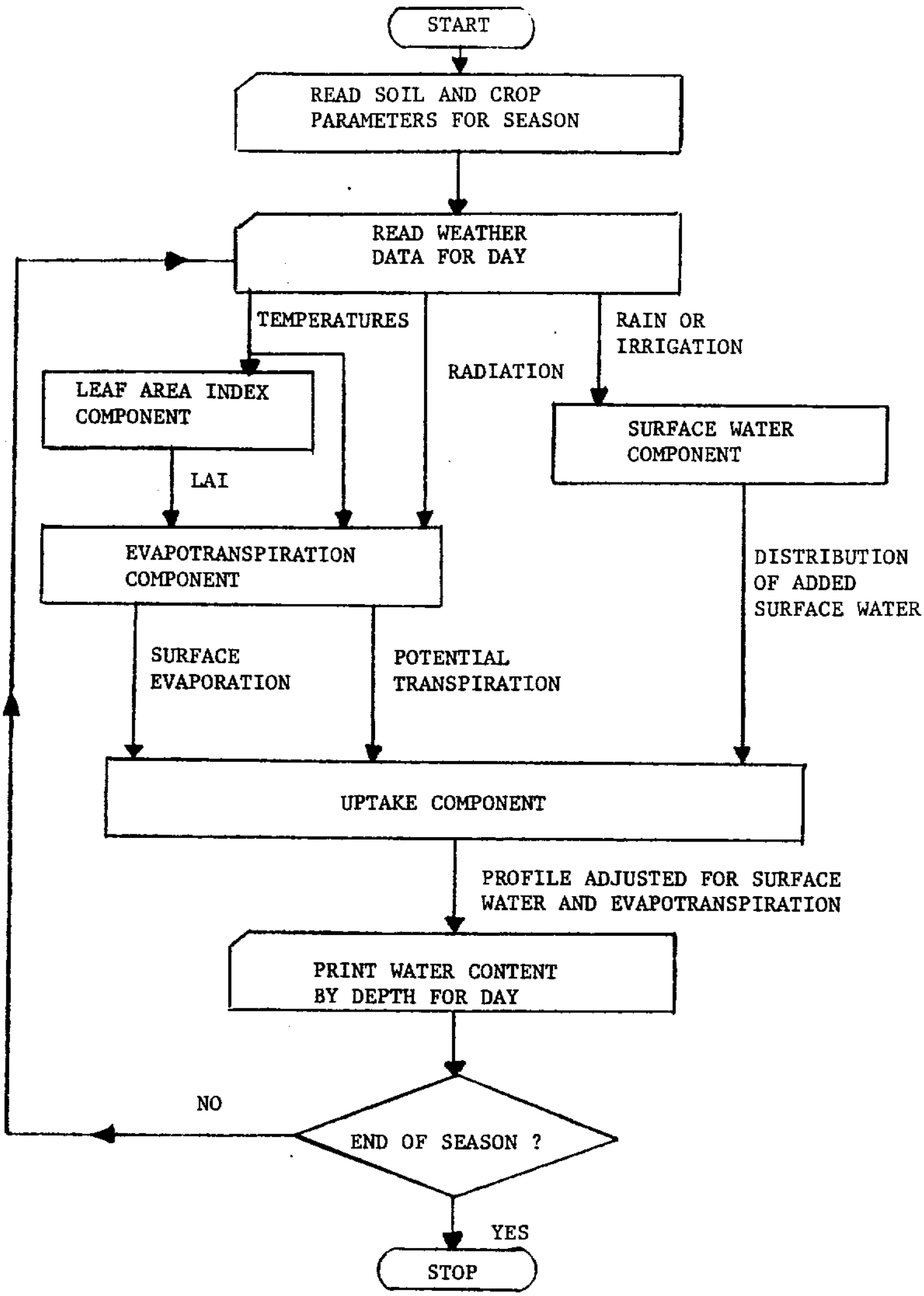

Figure 16. Flow Diagram of the Model

between predicted and actual water contents is best for the Maury soil. Average sums of squares of deviations between actual and predicted water contents are given in table 5.

The sums of squares for the Maury soil with conventional tillage ranged from 9 to 20 ($X10^{-4}$); with no tillage it ranged from 8 to 24 ($X10^{-4}$). For the Crider soil, the range was 22 to 28 ($X10^{-4}$). The most poorly predicted soil water contents were in the Lowell, where the sums of squares ranged from 78 to 253 ($X10^{-4}$). The overall accuracy of prediction for the intermediate soils was about one half to one third as good as for the Maury.

Of the soils that hold some excess water, the Calloway and Grenada soils fit the best. Part of their deviation from the model may be due to their being cropped to wheat in the spring, followed by soybeans in the summer. However, there was no consistent difference between soils cropped to corn and soils cropped to soybeans. It would seem that the different crops remove water from the soil in nearly identical patterns. The Zanesville water contents were not predicted well by the model, although the use of maximum observed water content as field capacity seemed to help in modeling the extra water in the perched water table. The model did not predict water contents at all well in the Shelbyville and Lowell soils. The combination of poor drainage, thinner profile and finer texture (subsoil?) was apparently too much for a model adapted to a Maury silt loam.

The Huntington soil (table 6) was not modeled well by the model in its original form, but simple modicications improved the accuracy of prediction considerably. It was first assumed that the maximum and minimum observed water contents did not reflect the actual field capacity and wilting point of the soil because of the presence of a water source at the bottom of the profile. Pressure plate water contents at -15 bars were used as wilting point values, and somewhat lower values were used for field capacity. The bottom layer was either eliminated or held at field capacity so it would imitate the water source, and only the top five layers were used in computing sums of squares of deviations of predicted from actual water contents. Accuracy of predictions increased to the point that the Huntington predictions were second in accuracy only to the Maury predictions.

The model works rather well on the well-drained soils (Maury, Crider) and on the soil with a permanent water table (Huntington), but more work will have to be done on the poorly drained soils (Zanesville, Shelbyville, Lowell). The intermediate soils (Grenada, Calloway) can be modelled, but judgement and caution must be exercised in interpreting the results.

TABLE 5

Average sums of squares of deviations (x 10,000) between actual and predicted volumetric water contents.

	1977	1978	1979	1980	TOTALS
Maury N T	14	8	23	24	69
Maury Conv.	9	11	14	20	54
Shelbyville	107	70	83	193	453
Lowell	144	78	253	185	660
Huntington	37	23	50	59	169
Crider	22	17	22	28	89
Zanesville	27	39	39	57	162
Grenada	99	70	19	60	248
Calloway	55	53	15	31	154
TOTALS	514	369	518	657	

TABLE 6

Comparison of deviation sums of squares for three assumptions about Huntington soil.

ASSUMPTION	YEAR 1977	1978	1979	1980	TOTALS
Original model	37	23	50	59	169
75 to 90 cm layer eliminated	23	17	30	30	100
75 to 90 cm layer at field capacity	20	19	15	14	68

D. Comparing Predicted Deep Drainage with Streamflow;

The prediction of deep drainage from the soil water model used in this study and its comparison with measured stream flow was carried out in some detail for the growing seasons of 1978 and 1979 (a dry and excessively wet year respectively) on the Grenada, Crider, Zanesville and Maury soils. Each of these soils is located near a small watershed gauged by the U.S. Geological Survey. In the case of the Maury, the stream was South Elkhorn Creek; with Grenada, it was the West Fork of Clarks River and with the Crider and Zanesville soils, the stream was Muddy Fork of the Little River. Because the Crider and Zanesville soils have markedly different water storage, each was compared separately although the watershed contains both soils and should act as a sort of average of both.

The results of predicted deep drainage vs. the streamflow events that raised the flow above "base flow", or the steady background are presented in tables 7 through 9. Table 7, for Maury, in 1978 and 1979 represents as good a fit as was obtained. The value for R^2 was 0.71, meaning that 71% of the variation was explained by the model. The slope of the prediction, however, was 1.84 meaning that the model predicts nearly twice as much flow as actually occurred.

The streamflow predicted by the Grenada deep drainage for 1978 and 1979 is shown in table 8. Here, the prediction is less favorable than with the Maury since the percentage of the variation explained by the regression is only 41%. The slope was 0.62, meaning that the model underpredicted flow. (most of this was caused by the storm September 20-22, 1979).

The Crider and Zanesville (table 9) had R^2 values of 95% and 92%, respectively, and b values of 1.36 and 1.08, suggesting that the predictability was excellent. Unfortunately, this was only true for one large event which so biased the data that the errors for small events are completely overshadowed. In general, the predictability probably was no better than with the other soils, at least for smaller events.

There appear to be several reasons for the errors (or unexplained variation) in the model. At least one of these errors is outside the control of the model: Variable rainfall in the watershed. If there is a rainstorm on part of the watershed, but which is not recorded at the reference rain gauge, there likely will be a stream flow that is unexplained by the model. Such a case occurred on Aguust 8-9, 1979 on the Crider-Zanesville soils when there was appreciable stream-flow and no rain at all. No model can deal with this problem.

There are other problems, however, inherent in the model. From examining the predicted vs. the real occurrences, it appears that the model has the following limitations: (1) There is no provision for ground water storage; all water is predicted to be delivered to the stream on a daily basis. Obviously, the assumption is not true and is extremely variable from site to site and soil to soil. Unfortunately, at this time, knowing no more about the hydraulic properties of the various substances than we do, there is no realistic substitute that can be used. (2) There needs to be a foliage evaporation correction, particularly for small rainfall events.

This condition would negate many small rains as sources of stream flow. (3) The present model allows too much water to flow through the soil for small rainfall events on fairly dry soils. This error works in the same direction as the previous one by predicting deep drainage when none, in fact, occurs. (4) The predicted evapotranspiration slows down too fast as soils are dried out. This, in turn, predicts wetter soils than actually found and also helps predict too much deep drainage as do points 2 and 3 above.

Thus there are two kinds of errors involved. The first kind, ground water storage and variable rainfall can be solved only by resorting to more measurements of springs, ground water levels and rainfall characterize the watershed. The others are built into the model and can be improved and we expect to make these improvements in the future. We are left with a nagging feeling, however, that there will always be a high degree of uncertainty because of the need for accurate measurements regardless of the model used.

The model used in this study does <u>not</u> require that the soil profile be in excess of field capacity before deep drainage occurs as so many do. Hence, it does a rather good job of predicting the <u>occurrence</u> of streamflow events that other models ignore or attribute to overland flow. The quantitative prediction is only mediocre, however.

The field measurement of overland flow with homemade weirs and inadequate labor proved to be beyond our reach. Qualitatively, we can say that there are very few events during the summer in which overland flow markedly affects streamflow. By far the most of the flow occurs because of deep drainage through soils and the subsequent delivery to streams through ground water aquifers and/or underground streams. Overland flow has been oversold as the cause of streamflow events in general, and certainly in Kentucky in particular. Future studies would do well to consider deep drainage more seriously.

TABLE 7

Predicted and observed streamflow from South Elkhorn Creek (Maury Soil)

DATE	PREDICTED STREAMFLOW Cm H_2O	OBSERVED STREAMFLOW Cm H_2O
1978		
May 23, 24	1.14	1.49
June 3 - 8	0.97	0.09
July 26, 27	0.42	0.14
July 31	0	1.23
August 4, 5	0.35	0.24
August 10 - 12	0.60	0.90
August 17	0.19	0.20
August 24	0.58	0.92
August 29, 30	2.60	3.22
1979		
June 7 - 10	1.87	1.57
June 29	0.40	0.33
July 12, 13	0.47	0.13
July 22, 23	1.55	0.02
July 25 - 27	2.28	1.57
August 11	0	0.15
August 20	0.38	0.39
August 29, 30	0.23	0.90
September 13	2.11	2.36
September 21, 22	9.63	5.60
September 27	2.94	1.89

TABLE 8

Predicted and observed streamflow from West Fork, Clarks River (Grenada Soil).

DATE	PREDICTED FLOW, Cm H_2O	OBSERVED FLOW, Cm H_2O
1978		
May 29, 30	0.19	0.16
June 18	0.25	0.07
July 9	0.27	0.24
July 31	0.01	0.03
August 11	5.03	0.97
August 22	0.06	0.10
August 29 - 31	2.24	0.03
1979		
June 20, 23	0.61	3.27
July 1	0.16	0.31
July 8, 9	1.19	0.10
July 12	0.11	0.26
July 23 - 28	1.20	0.31
August 11	0.25	0.10
August 21	0.18	0.12
August 25 - 28	0.60	0.30
August 30	0.22	0.90
September 20 - 22	4.59	6.25

TABLE 9

Predicted and observed streamflow from Muddy Fork, Little River (Crider and Zanesville soils)

DATE	PREDICTED STREAMFLOW Cm H_2O (CRIDER)	PREDICTED STREAMFLOW Cm H_2O (ZANESVILLE)	OBSERVED STREAMFLOW Cm H_2O
1978			
Aug. 8, 9	0	0	0.24
Aug. 10-12	0.67	0.22	0.90
Aug. 26	0.27	0.29	0.01
Aug. 30-31	0.78	0.33	0.06
1979			
May 20-24	1.42	1.19	0.07
May 28	0.49	0.49	0.35
June 24	0.25	0.10	0.05
July 13	0.35	0.06	0.02
July 22	0.01	0.28	0.02
Aug. 22-28	0.73	1.17	0.03
Sept. 13, 14	1.14	0.69	0.48
Sept. 21	8.49	6.99	6.10

SUMMARY AND CONCLUSIONS

Water contents of eight important soil series in Kentucky were determined over four summer growing seasons. The wetting and drying patterns revealed that the soils divided into three groups: Group one (Maury, Crider) was well drained and never showed evidence of excess water in the profile; group two (Zanesville, Lowell, Calloway, Grenada and Shelbyville) had perched water tables in the profile during part of the growing season; and group three (Huntington) showed evidence of a permanent water table influence on soil water throughout the season.

In-situ field capacity determinations on three soil series (Maury, Shelbyville and Crider) revealed that the soil series has a rather uniform value in the field. This, in turn, means that predictions of water contents made on one site can be carried to other sites with the same soil if the rainfall is known.

A model for estimating soil water was developed and used on all soils for the four years. Maury and Crider soils gave good fit between the predicted and observed values, whereas the Lowell gave a rather poor fit. The model is a simple one and inexpensive to run on the computer. In general, it gives good overall results, but certain improvements are needed to make it more quantitative.

The model also was used to predict stream flow, using the amount of water calculated as deep drainage as the "rise in streamflow". These calculated values were compared for 1978 and 1979 with three streams and four soils. The R^2 values ran between 0.41 and 0.95 and slopes (b) ranged from 0.54 to 1.36. Quantitative prediction of streamflow events was mediocre, but qualitative prediction was very good. Modifications that need to be made in the model include a "storage" factor and some corrections for evaporation from foliage, evapotranspiration from dry soils and deep drainage from light rains.

As a result of the work done on this project, there is a published model for soil water which works reasonably well. In addition, we have very good data on upper and lower limits of water contents in eight soils which represent an important part of Kentucky's surface area. The attempt to model streamflow was only moderately successful, but it is clear what limitations remain and what needs to be done to modify the model to predict this better. Finally, this project work brought out very forcefully, the need for more careful and comprehensive rainfall data as a basis for model, such as this one. As the work progressed, it became clear that inadequate rainfall data are the most serious drawback to successful soil water modeling.

LITERATURE CITED

Denmead, O. T. and R. H. Shaw. 1962 Availability of soil water to plants as affected by soil moisture content and meteorological conditions. Agron J. 54:385-390.

Duncan, W. G. and J. D. Hesketh. 1969. Net photosynthetic rates, relative leaf growth rate, and leaf number of maize grown at eight temperatures. Crop. 8ci. 8:670-674.

Duncan, W. G., G. W. Thomas and R. E. Phillips. 1974. Simulation of daily soil moisture profiles over four seasons using two tillage methods. Agron. Abstracts p.13.

Penman, H. L. 1948. Natural evaporation from open water, base soil and grass. Proc. Royal Soc. London 193:120:145.

Radcliffe, D., T. Hayden, K. Watson, P. Crowley, and R. E. Phillips. 1980. Simulation of soil water within the root zone of a corn crop. Agron. J. 72: 19-24.

Ritchie, J. T. 1972. Model for predicting evaporation from a row crop with incomplete cover. Water Resources Res. 18:1204-1213.

Thomas, G. W., R. E. Phillips and V. L. Quisenberry. 1978. Characterization of water displacement in soils using simple chromatographic theory. J. Soil Sci. 29:32-37.

Wadleigh, C.H. 1945. The integrated soil moisture stress upon a root system in a large container of saline soil. Soil Sci. 60:225-238.

MAURY NO TILL 1977

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-34	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
147	2.92	.18	.21	.25	.31	.34	.00	19.5
159	2.29	.29	.27	.28	.32	.35	.00	22.5
175	8.38	.32	.30	.29	.33	.35	.00	23.7
187	4.44	.30	.29	.31	.34	.38	.00	24.4
200	.00	.23	.23	.26	.32	.35	.00	20.8
214	3.43	.22	.17	.21	.28	.33	.00	18.2
228	11.56	.33	.32	.32	.31	.32	.00	24.0
243	4.57	.36	.32	.30	.32	.32	.00	24.3
256	2.41	.27	.25	.26	.29	.31	.00	20.7

TOTAL RAIN 42.67 CM

MAURY NO TILL 1978

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-34	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
179	9.30	.26	.27	.29	.33	.35	.00	22.3
196	2.34	.22	.19	.24	.29	.32	.00	19.0
209	4.57	.20	.17	.20	.27	.31	.00	17.1
222	5.72	.30	.28	.25	.29	.33	.00	21.7
238	6.73	.31	.29	.29	.31	.33	.00	23.1
252	5.46	.31	.29	.30	.34	.37	.00	24.2

TOTAL RAIN 34.49 CM

MAURY NO TILL 1979

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-34	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
136	.00	.32	.27	.29	.33	.36	.00	23.6
150	5.59	.33	.37	.30	.33	.35	.00	25.2
165	5.21	.33	.33	.33	.36	.38	.00	25.9
178	2.03	.30	.29	.30	.34	.38	.00	24.0
198	3.68	.34	.33	.32	.34	.36	.39	31.2
214	12.32	.34	.31	.31	.34	.36	.38	30.5
223	2.16	.24	.19	.27	.30	.31	.37	25.3
250	8.81	.28	.26	.26	.30	.32	.34	26.6
255	6.98	.24	.22	.24	.29	.32	.33	24.7
269	15.70	.34	.32	.32	.35	.38	.39	31.4

TOTAL RAIN 52.48 CM

MAURY NO TILL 1980

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-34	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
136	.00	.26	.26	.28	.33	.36	.37	28.0
137	1.65	.23	.24	.27	.32	.35	.38	26.8
141	2.16	.35	.30	.29	.31	.35	.36	29.3
155	1.65	.28	.26	.28	.32	.35	.36	27.8
169	.89	.30	.27	.29	.33	.36	.36	28.7
183	3.73	.27	.25	.27	.31	.34	.36	27.1
197	13.72	.29	.26	.28	.33	.36	.36	28.3
217	10.87	.30	.25	.25	.30	.34	.36	27.0
225	2.54	.28	.24	.27	.32	.35	.38	27.7
241	3.05	.15	.16	.20	.26	.30	.32	20.9
253	3.38	.20	.16	.20	.26	.30	.31	21.8

TOTAL RAIN 55.19 CM

MAURY CONVENTIONAL 1977

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
147	2.92	.26	.27	.29	.31	.33	.00	22.0
159	2.29	.25	.28	.28	.31	.34	.00	22.0
175	8.38	.26	.26	.28	.31	.33	.00	21.6
187	4.44	.25	.28	.29	.33	.35	.00	22.5
200	.00	.19	.21	.24	.29	.32	.00	18.7
214	3.43	.20	.18	.21	.27	.30	.00	17.3
228	11.56	.29	.30	.29	.29	.30	.00	22.2
243	4.57	.30	.29	.28	.30	.30	.00	22.0
256	2.41	.21	.23	.25	.27	.29	.00	18.8

TOTAL RAIN 42.67 CM

MAURY CONVENTIONAL - 1978

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
179	9.30	.26	.00	.29	.32	.35	.00	18.3
196	2.34	.20	.19	.21	.23	.26	.00	16.4
209	4.57	.19	.17	.21	.26	.30	.00	16.9
222	5.72	.26	.30	.27	.29	.31	.00	21.6
238	6.73	.25	.26	.27	.29	.31	.00	20.9
252	5.46	.26	.29	.30	.33	.34	.00	22.7

TOTAL RAIN 34.49 CM

MAURY CONVENTIONAL 1979

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
136	.00	.25	.28	.30	.32	.34	.00	22.3
150	5.59	.23	.28	.29	.32	.33	.00	21.6
165	5.21	.28	.29	.31	.34	.35	.00	23.7
178	2.03	.22	.25	.29	.32	.34	.00	21.3
198	3.68	.22	.22	.25	.30	.35	.37	25.5
214	12.32	.27	.30	.29	.32	.35	.37	28.6
223	2.16	.21	.20	.23	.30	.33	.32	24.0
250	8.81	.24	.25	.26	.28	.31	.34	25.2
255	6.98	.21	.22	.24	.28	.31	.33	23.8
269	15.70	.29	.30	.32	.35	.36	.37	29.8

TOTAL RAIN 62.48 CM

MAURY CONVENTIONAL 1980

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
136	.00	.22	.26	.29	.32	.35	.36	27.0
141	3.81	.31	.31	.32	.34	.37	.36	30.0
155	1.65	.21	.25	.28	.31	.34	.35	26.2
169	.89	.20	.24	.27	.32	.34	.36	26.1
183	3.73	.19	.21	.25	.30	.33	.34	24.2
197	13.72	.19	.26	.25	.29	.32	.34	24.8
217	10.87	.26	.23	.25	.29	.26	.34	24.6
225	2.54	.28	.26	.27	.31	.32	.35	26.7
241	3.05	.10	.15	.21	.26	.29	.31	19.7
253	3.38	.21	.17	.22	.26	.29	.32	22.1

TOTAL RAIN 55.19 CM

SHELBYVILLE 1977

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
137	1.07	.27	.20	.35	.38	.38	.43	30.1
153	6.73	.24	.27	.32	.37	.36	.00	23.4
165	.51	.20	.22	.28	.33	.35	.38	26.5
179	2.21	.32	.32	.36	.39	.39	.43	32.9
193	5.05	.32	.30	.32	.37	.36	.39	31.0
207	8.20	.33	.28	.30	.34	.35	.38	29.7
221	4.19	.27	.27	.33	.36	.37	.40	30.1
236	7.11	.35	.32	.35	.39	.37	.39	32.6

TOTAL RAIN 50.32 CM

SHELBYVILLE 1978

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
147	7.32	.34	.35	.40	.43	.41	.44	35.5
158	.64	.26	.29	.35	.40	.39	.44	32.1
188	11.46	.26	.29	.34	.39	.38	.41	31.0
202	8.43	.24	.26	.32	.37	.37	.40	29.5
216	7.04	.32	.35	.38	.41	.39	.38	33.6
230	1.19	.29	.31	.36	.39	.36	.37	31.2
244	9.80	.35	.35	.39	.43	.41	.40	34.9

TOTAL RAIN 55.50 CM

SHELBYVILLE 1979

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
136	.99	.38	.48	.36	.49	.45	.00	32.4
153	2.46	.35	.31	.35	.38	.37	.38	31.9
166	11.05	.31	.30	.36	.39	.36	.37	31.4
177	.51	.21	.24	.30	.33	.28	.36	25.7
198	6.07	.27	.40	.47	.47	.43	.00	30.5
212	14.10	.34	.34	.38	.40	.37	.00	27.4
222	10.34	.39	.34	.44	.39	.29	.00	27.8
245	17.25	.39	.46	.50	.44	.39	.42	38.9
260	14.68	.36	.33	.37	.41	.41	.39	34.0
273	9.27	.36	.34	.38	.42	.39	.39	34.3

TOTAL RAIN 106.07 CM

SHELBYVILLE 1980

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
136	.63	.25	.26	.32	.37	.38	.40	29.6
149	6.12	.22	.26	.31	.35	.36	.36	27.9
162	2.06	.18	.20	.26	.33	.32	.33	24.3
176	3.53	.22	.17	.23	.29	.32	.33	23.6
190	10.39	.25	.25	.25	.28	.31	.34	25.4
205	5.64	.32	.30	.28	.28	.28	.30	26.4
218	4.24	.29	.30	.35	.37	.42	.47	33.0
232	6.07	.32	.28	.30	.33	.31	.31	28.0
234	3.86	.34	.33	.40	.42	.42	.40	34.6
247	3.38	.25	.38	.43	.42	.00	.00	22.1
261	3.51	.17	.17	.22	.25	.27	.34	21.4
275	1.32	.17	.18	.23	.26	.29	.39	22.8

TOTAL RAIN 55.17 CM

LOWELL 1977

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
137	1.07	.35	.39	.41	.40	.40	.45	36.2
153	6.73	.32	.39	.49	.49	.50	.00	32.8
165	.51	.27	.28	.33	.36	.42	.44	31.4
179	2.21	.41	.43	.51	.51	.51	.50	43.1
193	5.05	.41	.41	.49	.49	.49	.46	41.2
207	8.20	.41	.48	.53	.48	.47	.49	42.8
221	4.19	.37	.38	.49	.48	.49	.46	40.0
236	7.11	.40	.41	.50	.48	.48	.46	41.0

TOTAL RAIN 50.32 CM

LOWELL 1978

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
147	7.32	.46	.57	.61	.50	.53	.54	48.3
158	.64	.37	.54	.55	.49	.51	.00	36.8
188	11.46	.35	.40	.52	.50	.48	.49	41.2
202	8.43	.33	.43	.52	.45	.38	.00	31.5
216	7.04	.42	.48	.57	.50	.43	.41	42.2
230	1.19	.38	.38	.51	.47	.45	.00	32.8
244	9.80	.42	.48	.55	.49	.44	.00	35.6

TOTAL RAIN 55.50 CM

LOWELL 1979

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
136	.99	.31	.30	.36	.39	.39	.43	32.6
153	2.46	.43	.50	.55	.50	.52	.51	45.2
166	11.05	.35	.47	.52	.44	.43	.38	38.9
177	.51	.22	.40	.47	.41	.27	.00	26.4
198	6.07	.35	.34	.41	.41	.35	.45	34.8
212	14.10	.40	.49	.53	.48	.47	.00	35.6
222	10.34	.26	.32	.31	.35	.38	.00	24.2
245	17.25	.34	.33	.36	.40	.39	.38	33.0
260	14.68	.37	.47	.54	.45	.30	.00	32.0
273	9.27	.42	.53	.51	.39	.00	.00	27.8

TOTAL RAIN 106.07 CM

LOWELL 1980

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
136	.63	.30	.44	.52	.49	.48	.00	33.5
149	6.12	.29	.44	.50	.46	.45	.00	32.0
162	2.06	.28	.41	.44	.42	.44	.00	29.8
176	3.53	.37	.40	.41	.33	.32	.00	27.5
190	10 39	.33	.41	.45	.40	42	47	37.4
205	5.64	.39	.43	.49	.45	.45	.00	33.2
218	4.24	.34	.48	.53	.46	.49	.52	42.4
232	6.07	.39	.48	.54	.43	.00	.00	27.6
234	3.86	.49	.55	.64	.59	.61	.00	43.0
247	3.38	.26	.27	.31	.31	.37	.44	29.3
261	3.51	.32	.45	.50	.43	.39	.00	31.4
275	1.32	.32	.46	.51	.45	.48	.00	33.4

TOTAL RAIN 55.17 CM

HUNTINGTON 1977

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
139	.00	.36	.37	.37	.45	.41	.42	35.7
153	.61	.33	.35	.35	.41	.41	.43	34.2
165	.84	.32	.36	.34	.42	.40	.41	33.6
179	11.02	.42	.37	.36	.45	.42	.43	36.7
193	4.42	.34	.34	.33	.42	.41	.43	34.0
209	.63	.43	.40	.37	.43	.41	.43	37.1
221	2.87	.31	.34	.34	.41	.39	.42	33.2
235	19.48	.42	.39	.37	.46	.43	.44	37.8
252	8.64	.32	.34	.35	.44	.41	.43	34.3
263	2.44	.43	.39	.35	.44	.41	.41	36.5

TOTAL RAIN 60.10 CM

HUNTINGTON 1978

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
137	2.16	.45	.42	.38	.47	.48	.56	41.4
152	4.52	.38	.40	.36	.45	.44	.47	37.5
165	4.04	.32	.37	.35	.43	.42	.44	34.8
174	1.88	.31	.38	.34	.43	.42	.45	35.1
179	.00	.32	.37	.36	.44	.42	.43	35.0
202	2.41	.32	.37	.36	.45	.42	.43	35.2
216	1.50	.29	.33	.32	.40	.38	.41	32.0
230	4.01	.31	.33	.30	.34	.33	.35	29.3
244	12.19	.47	.45	.40	.43	.39	.41	38.1
292	5.56	.35	.36	.36	.44	.38	.36	33.9
305	2.46	.44	.44	.36	.41	.38	.39	36.3

TOTAL RAIN 40.74 CM

HUNTINGTON 1979

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
136	1.45	.38	.40	.36	.47	.45	.45	37.7
152	3.48	.40	.36	.36	.45	.42	.44	36.4
166	11.79	.28	.34	.35	.45	.42	.44	34.1
179	2.67	.30	.33	.34	.42	.40	.43	33.4
192	1.57	.28	.31	.31	.39	.39	.41	31.2
205	8.92	.39	.35	.34	.42	.39	.40	34.2
220	20.52	.37	.36	.35	.45	.43	.43	36.0
234	2.26	.29	.30	.31	.41	.40	.42	32.1
264	11.07	.33	.33	.34	.40	.39	.39	32.9

TOTAL RAIN 81.53 CM

HUNTINGTON 1980

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	WATER IN PROFILE
142	5.08	.44	.40	.39	.44	.40	.43	37.6
156	9.47	.31	.37	.37	.44	.39	.42	34.6
170	2.62	.30	.34	.35	.41	.37	.41	32.7
183	13.67	.43	.44	.38	.44	.40	.42	37.6
197	4.39	.29	.33	.33	.39	.37	.42	31.9
211	8.71	.42	.41	.37	.43	.40	.41	36.5
224	1.22	.32	.34	.29	.37	.34	.37	30.4
239	3.48	.31	.34	.33	.37	.33	.37	30.5
250	1.78	.30	.31	.30	.35	.33	.34	28.9
300	11.38	.41	.39	.38	.44	.39	.41	36.2

TOTAL RAIN 63.40 CM

CRIDER 1977

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
139	.00	.23	.25	.31	.32	.34	.34	27.0
153	4.39	.22	.27	.32	.34	.38	.37	28.7
166	2.03	.16	.20	.27	.31	.37	.39	25.7
179	6.05	.29	.27	.31	.34	.37	.40	29.7
193	10.92	.27	.23	.28	.32	.36	.39	27.8
207	.99	.14	.13	.17	.23	.29	.33	19.2
223	6.96	.16	.20	.20	.29	.34	.33	22.7
234	15.98	.32	.30	.35	.36	.38	.38	31.3
252	2.74	.26	.26	.32	.33	.36	.37	28.4

TOTAL RAIN 54.66 CM

CRIDER 1978

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
137	.71	.34	.34	.39	.41	.42	.44	35.0
153	2.16	.28	.29	.34	.38	.41	.44	32.1
166	2.06	.23	.25	.32	.35	.38	.39	28.8
172	.30	.22	.21	.32	.34	.36	.37	27.1
173	.71	.25	.26	.34	.38	.36	.41	29.9
187	.00	.24	.25	.39	.33	.37	.37	29.2
192	.30	.15	.18	.25	.30	.31	.32	22.7
249	13.67	.22	.23	.24	.28	.27	.28	22.9
264	1.02	.16	.17	.21	.26	.26	.26	19.9
278	2.24	.19	.15	.19	.24	.26	.26	19.4
291	1.50	.18	.15	.21	.25	.27	.26	19.8
305	2.39	.21	.16	.19	.27	.33	.37	22.8

TOTAL RAIN 27.05 CM

CRIDER 1979

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
136	.00	.28	.28	.32	.36	.39	.41	30.6
152	5.00	.34	.32	.38	.40	.42	.43	34.4
166	4.34	.31	.29	.34	.37	.40	.42	31.9
179	.66	.27	.27	.33	.37	.40	.42	30.9
191	.89	.28	.26	.32	.37	.40	.41	30.6
205	4.29	.21	.21	.28	.35	.38	.40	27.4
219	2.36	.25	.25	.30	.34	.38	.39	28.6
233	5.99	.35	.28	.33	.35	.37	.39	30.8
249	8.36	.29	.28	.33	.36	.38	.38	30.3
264	20.95	.31	.29	.35	.39	.40	.42	32.3

TOTAL RAIN 53.04 CM

CRIDER 1980

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
142	4.52	.31	.31	.36	.39	.40	.42	32.9
155	5.54	.27	.29	.34	.38	.41	.42	31.5
169	.00	.21	.24	.30	.36	.39	.40	28.7
183	8.64	.26	.26	.31	.35	.38	.40	29.5
197	4.32	.17	.17	.25	.33	.37	.38	25.1
212	3.71	.17	.16	.22	.29	.34	.37	23.0
225	3.81	.14	.14	.22	.26	.30	.34	21.0
239	.33	.10	.11	.18	.25	.27	.29	17.9
250	2.34	.13	.11	.18	.24	.26	.26	17.7
300	19.34	.27	.26	.29	.28	.27	.27	24.6

TOTAL RAIN 54.31 CM

ZANESVILLE 1977

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
139	.00	.31	.36	.37	.42	.44	.38	34.2
153	4.39	.30	.35	.36	.40	.44	.38	33.4
166	2.03	.27	.32	.33	.37	.40	.37	31.1
179	6.05	.36	.34	.37	.39	.41	.38	33.7
193	10.92	.35	.34	.36	.39	.42	.38	33.6
207	.99	.24	.26	.29	.36	.38	.37	28.4
223	6.96	.26	.28	.29	.33	.38	.36	28.4
234	15.98	.36	.38	.41	.44	.44	.38	36.2
252	2.74	.34	.37	.38	.44	.48	.39	35.9

TOTAL RAIN 54.66 CM

ZANESVILLE 1978

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
137	.71	.37	.39	.44	.48	.55	.47	40.4
153	2.16	.32	.35	.38	.44	.50	.43	36.4
166	2.06	.28	.32	.35	.40	.47	.40	33.4
172	.30	.27	.32	.33	.40	.44	.41	32.6
173	.71	.32	.35	.37	.42	.50	.41	35.4
187	.00	.28	.26	.30	.32	.39	.36	28.6
192	.30	.25	.29	.33	.39	.36	.31	29.0
249	13.67	.16	.18	.18	.20	.22	.28	18.2
264	1.02	.23	.19	.20	.22	.28	.29	21.3
278	2.24	.22	.16	.18	.22	.25	.28	19.5
291	1.50	.24	.21	.21	.24	.27	.26	21.5
305	2.39	.38	.31	.38	.43	.47	.42	35.9

TOTAL RAIN 27.05 CM

ZANESVILLE 1979

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
136	.00	.31	.34	.38	.44	.51	.42	35.9
152	5.00	.35	.34	.39	.45	.50	.45	37.3
166	4.34	.27	.32	.36	.41	.47	.40	33.5
179	.66	.27	.30	.32	.36	.39	.37	30.1
191	.89	.26	.29	.32	.36	.40	.35	29.6
205	4.29	.24	.26	.30	.43	.39	.37	29.8
219	2.36	.21	.25	.26	.31	.35	.32	25.5
234	9.17	.31	.27	.27	.30	.36	.34	27.7
249	5.18	.18	.19	.21	.26	.33	.32	22.3
264	20.95	.28	.30	.30	.28	.27	.31	26.2

TOTAL RAIN 53.04 CM

ZANESVILLE 1980

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
142	4.52	.31	.34	.39	.43	.46	.38	34.6
155	5.54	.30	.31	.37	.43	.46	.39	33.8
169	.00	.26	.31	.34	.39	.42	.35	31.2
183	8.64	.31	.31	.32	.36	.39	.36	31.0
197	4.32	.22	.25	.27	.34	.39	.34	27.2
212	3.71	.26	.26	.29	.33	.38	.35	28.2
225	3.81	.22	.21	.22	.28	.35	.34	24.3
239	.33	.14	.14	.16	.19	.26	.31	18.0
250	2.34	.14	.15	.16	.19	.27	.28	17.9
300	19.84	.31	.33	.34	.35	.35	.32	30.2

TOTAL RAIN 54.31 CM

GRENADA 1977

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
140	.00	.11	.19	.26	.31	.31	.33	22.8
153	4.17	.10	.13	.21	.30	.32	.33	20.9
166	.00	.07	.13	.16	.25	.29	.31	18.2
180	11.86	.24	.18	.17	.26	.31	.34	22.4
193	4.06	.18	.22	.21	.27	.30	.33	22.6
208	2.13	.22	.21	.22	.29	.32	.35	24.1
222	3.00	.22	.27	.29	.32	.31	.33	26.1
235	3.81	.22	.25	.24	.27	.29	.31	23.7
252	4.55	.10	.16	.19	.25	.28	.29	18.8
263	7.77	.29	.29	.24	.26	.28	.32	25.3
277	11.10	.33	.35	.36	.38	.38	.39	32.8

TOTAL RAIN 56.97 CM

GRENADA 1989

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
138	.00	.36	.35	.34	.37	.34	.35	31.7
152	.41	.29	.33	.32	.34	.32	.32	28.7
166	1.93	.27	.31	.31	.34	.32	.33	28.3
178	2.49	.19	.26	.27	.32	.31	.33	25.3
187	.30	.16	.27	.28	.31	.30	.33	24.6
192	.81	.23	.29	.28	.33	.31	.34	26.4
214	2.18	.18	.28	.27	.32	.29	.32	24.8
224	12.83	.32	.25	.28	.31	.30	.32	26.5
249	12.19	.16	.21	.22	.26	.27	.32	21.6
264	2.41	.10	.16	.18	.20	.22	.27	16.8
278	1.70	.15	.18	.18	.19	.22	.27	17.7
291	1.22	.21	.18	.16	.21	.24	.30	19.7
305	3.15	.22	.20	.17	.19	.21	.24	18.4

TOTAL RAIN 41.63 CM

GRENADA 1979

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
136	.00	.34	.35	.36	.40	.37	.38	33.1
152	10.97	.38	.37	.37	.40	.41	.43	35.2
166	1.52	.22	.28	.31	.34	.35	.35	27.9
179	6.32	.30	.31	.32	.35	.35	.36	29.9
191	7.47	.35	.37	.37	.39	.36	.37	33.0
205	5.00	.33	.36	.36	.38	.33	.34	31.6
219	3.78	.29	.33	.35	.36	.33	.34	29.9
233	2.36	.22	.28	.18	.38	.38	.34	27.4
249	5.87	.25	.29	.31	.35	.33	.34	28.0
264	6.55	.26	.30	.31	.32	.31	.33	27.5

TOTAL RAIN 65.86 CM

GRENADA 1980

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
141	3.71	.30	.28	.27	.29	.30	.35	26.7
155	1.42	.25	.27	.26	.27	.30	.33	25.0
169	1.14	.16	.23	.24	.27	.26	.28	21.5
184	8.89	.29	.33	.32	.31	.26	.30	27.2
197	.30	.22	.27	.24	.27	.26	.27	23.0
211	7.34	.25	.30	.30	.30	.25	.30	25.7
225	3.58	.38	.31	.31	.34	.31	.32	29.6
239	.00	.19	.25	.26	.29	.28	.30	23.6
251	10.54	.28	.22	.21	.26	.27	.28	22.9
300	20.55	.33	.34	.33	.36	.28	.29	28.9

TOTAL RAIN 59.77 CM

CALLOWAY 1977

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
140	.00	.12	.18	.23	.33	.32	.34	22.9
153	4.17	.14	.19	.21	.30	.33	.35	22.8
166	.00	.07	.13	.16	.29	.31	.36	19.7
180	11.86	.29	.27	.20	.29	.31	.35	25.7
193	4.06	.21	.26	.24	.30	.32	.35	25.1
208	2.13	.24	.21	.23	.29	.32	.35	24.7
222	3.00	.17	.18	.21	.28	.30	.34	22.3
235	3.81	.24	.27	.25	.32	.32	.33	25.9
252	4.55	.10	.15	.18	.24	.26	.30	18.4
263	7.77	.31	.27	.19	.26	.30	.34	25.1
277	11.10	.36	.37	.36	.37	.37	.42	33.8

TOTAL RAIN 56.97 CM

CALLOWAY 1978

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
138	.00	.33	.34	.34	.38	.37	.39	32.1
152	.41	.25	.31	.31	.37	.36	.37	29.5
166	1.93	.23	.29	.31	.35	.34	.38	28.6
178	2.49	.00	.27	.29	.32	.31	.35	22.8
187	.30	.22	.29	.27	.30	.27	.27	24.5
192	.81	.18	.25	.27	.31	.30	.33	24.5
214	2.18	.18	.25	.27	.33	.32	.36	25.7
224	12.83	.34	.19	.22	.25	.28	.34	24.4
249	12.19	.20	.21	.19	.21	.24	.30	20.4
264	2.41	.12	.17	.14	.21	.26	.29	17.8
278	1.70	.15	.16	.17	.22	.24	.28	18.2
291	1.22	.29	.28	.18	.20	.23	.24	21.2
305	3.15	.24	.19	.17	.19	.23	.26	18.9

TOTAL RAIN 41.63 CM

CALLOWAY 1979

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC DEPTH (CM) 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
136	.00	.30	.32	.34	.39	.37	.38	31.6
152	10.97	.35	.36	.34	.34	.36	.40	32.2
166	1.52	.21	.30	.31	.35	.35	.38	28.5
179	6.32	.34	.35	.35	.40	.38	.40	33.4
191	7.47	.36	.38	.37	.41	.38	.41	34.6
205	5.00	.35	.36	.34	.37	.35	.37	32.0
219	3.78	.31	.33	.32	.36	.35	.39	30.8
233	2.36	.20	.25	.29	.37	.39	.41	28.7
249	5.87	.31	.34	.32	.33	.27	.36	28.9
264	6.55	.31	.28	.32	.37	.36	.37	30.0

TOTAL RAIN 65.86CM

CALLOWAY 1980

JULIAN DATE	CM RAIN AFTER LAST SAMPLING	THETA VOLUMETRIC 0-15	15-30	30-45	45-60	60-75	75-90	TOTAL CM WATER IN PROFILE
141	3.71	.29	.30	.30	.35	.34	.34	28.8
155	1.42	.24	.28	.29	.35	.33	.33	27.2
169	1.14	.14	.21	.26	.33	.32	.33	23.9
184	8.89	.32	.35	.34	.39	.36	.36	31.8
197	.30	.28	.32	.32	.37	.36	.38	30.4
211	7.34	.27	.27	.31	.36	.36	.38	29.2
225	3.58	.21	.19	.21	.29	.31	.36	23.6
239	.00	.10	.15	.16	.23	.28	.32	18.6
251	10.54	.29	.22	.17	.22	.26	.31	22.1
300	20.55	.33	.34	.34	.36	.32	.32	30.2

TOTAL RAIN 59.77 CM